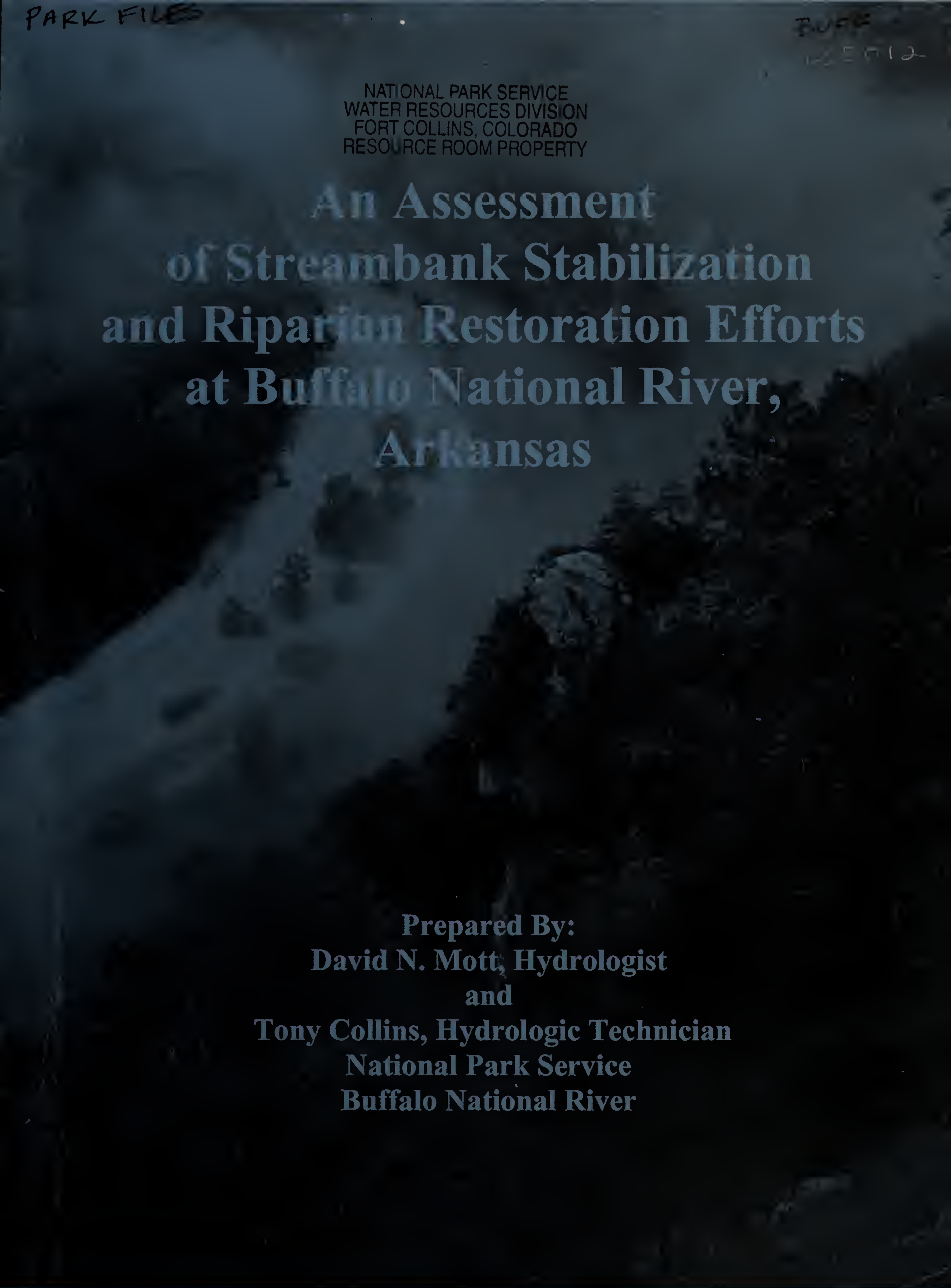

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An Assessment of Streambank Stabilization and Riparian Restoration Efforts at Buffalo National River, Arkansas

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An Assessment of Streambank Stabilization and Riparian Restoration Efforts at Buffalo National River, Arkansas

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National Park Service
Buffalo National River

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Executive Summary

Significant time and money is being expended by government and private parties to "restore" or "stabilize" streambanks and riparian areas and it is important to assess existing projects to improve future endeavors. This document provides a technically based review of streambank and riparian restoration projects implemented at Buffalo National River from 1990 – 2000. It also discusses some more recently installed "stabilization" projects. The purpose of this effort is to provide stream managers and specialists with an extensive case-study review. This report discusses: 1.) what the original problems were, 2.) what corrective measures were implemented and why, 3.) what worked and what didn't, 4.) specific factors that appear to influence success and failure, 5.) geomorphic and biotic responses to restoration, and 6.) applicability to other streams and rivers.

In 1994, Buffalo National River initiated a three-year streambank stabilization and riparian restoration project funded mainly by the National Park Service's Natural Resources Preservation Program. The purpose of this project was to stabilize eroding streambanks and riparian areas disturbed by agricultural clearing prior to the establishment of the National River in 1972, and in areas where agricultural operations are ongoing. Previous surveys and assessments identified 14 streambank restoration sites totaling 5,763 feet in length to be mitigated. We employed cedar revetments and other bioengineering practices wherever practical to mitigate the ongoing disturbance responsible for bank instability. We also identified 29 riparian zones totaling nearly 14 miles in length that needed buffer protection and restoration. Native seedlings were planted for three consecutive years, covering a total of 60 acres at these 29 sites.

Implementation of this strategy was determined to be the most appropriate for free-flowing streams and is in keeping with the management objectives for the river and the Boxley Valley National Historic District as stated in the Master Plan (1977) and the Boxley Land Use Plan (1985). The ability to protect park resources to the fullest possible extent while providing for the continued use of adjacent lands is a common need experienced by many National Rivers and Wild and Scenic Rivers within the Park System. Successful corridor restoration provides a positive model for other areas, although the exact methods and materials used in different physiographic regions are dependent on site specific factors.

Large restoration efforts taking place on federal lands involve many types of compliance. Significant time and resources were required to develop Corps of Engineers Section 404 permits and cultural resource compliance such as approval by the State Historic Preservation Office. Much time and effort was committed to archeological investigations which did not always result in clearance where pre-historic sites were identified proximal to restoration areas. Public involvement was also required as some of the concepts we sought to employ were fairly new to the area. After compliance came three years of intense labor. A total of 5,255 feet of cedar revetments were constructed at 12 sites, 8 of which were back-sloped and 4 of which were not back-sloped due to the previously mentioned archeological concerns. Back-sloping and vegetative transplanting alone were used at one additional site. We also established 12 miles of riparian corridor and replanted these corridors with native seedlings. Six miles of fence was constructed (either alone or cooperatively with park in-holders) along the reestablished riparian corridors to protect stream banks and riparian zones from cattle, and four alternative water sources (freeze proof tanks) were installed.

The report presents a detailed explanation of the various erosional processes observed along the Buffalo River and its tributaries and includes slope failure, scour, sheet and rill erosion. Erosional processes were typically exacerbated by riparian forest destruction, and propagation zone concepts are discussed in a general manner. Streambanks to be mitigated through this project were categorized based on their geomorphic properties. Grouping sites helped explain both the erosion processes occurring at these sites and the severity to which erosion can be expected to continue. Site groupings included confluence, channel modification, valley crossover/disturbance zones, massive slumping, and block failure sites.

Fourteen restoration sites are discussed in order from the upper-most site to the site furthest down river (covering a distance of 92 river miles). The discussion of each site begins with a pre-project site description that summarizes the condition of the bank , channel, and riparian zone prior to stabilization. Next, a project description section details what was done to stabilize and restore the streambank and riparian zone and why. Finally, we present a summary of project results section in which we describe how the bank and channel responded to the stabilization efforts. This section is often divided in upper, middle and lower thirds of the bank where these thirds are markedly different.

An assessment questionnaire is presented that is designed to provide a ready reference for the important questions that should be asked before determining if a cedar revetment is appropriate for an eroding streambank. A summary is provided of how each question is important, and attempts are made to put the questions into the context of "good" and "bad" indicators. Key indicators are defined and can be used to score the results of the Assessment Questionnaire.

Riparian buffer restoration efforts were evaluated by sampling 20' by 20' plots at 23 of the 29 restoration sites and by visual inspection of the remaining sites. There were 113,316 seedlings planted in 1995, 1996, and 1997 at the 23 sites assessed. A total of 60 acres of riparian buffer were planted amounting to 1,834 seedlings per acre. The overall survival rate for the seedlings planted was estimated at 40.6%.

The alternative techniques section provides a brief overview of some streambank stabilization techniques, other than cedar revetments, that have been implemented on the Buffalo River and tributaries. Techniques discussed include whole willow transplanting, gravel bar spawning through the use of willow transplanting in targeted hydrologic areas, and installation of rock vanes. These techniques were developed to augment cedar revetments or to use at those sites where completion of the Site Assessments Questionnaire indicated cedar revetments were not practical.

In summery, the streambank stabilization and riparian restoration efforts assessed in this report ranged from complete failures to great successes. This review documented that most sites were characterized by overall success. Six to eight years after their installation, 75 % of 5,255 feet of cedar revetments accomplished the goal of protecting streambanks long enough for native vegetation to colonize the bank and resume its natural role in bank stabilization. Eighty percent of the 60 acres of riparian zones we protected and replanted has a healthy re-growth of riparian vegetation. The six-miles of fencing we constructed in cooperation with park in-holders remains in-tact, although significant repairs were required after major floods along 40 percent of the fence.

Based on observations of the Buffalo River's hydrology and the fact that it is a high-velocity flash flood system, we conclude that cedar revetments are broadly applicable to a wide range of streams, and should work even better on less radical systems. The Assessment Questionnaire provides a standardized format to determine the applicability of cedar revetments to individual banks. While there is no substitute for direct field experience, the questionnaire appears to provide a sound means to examine potential issues at a given site and the overall score gives an indication of a cedar revetments likely success or failure.

The geomorphic and biological assessments performed as part of this review both indicate that cedar revetments improve stream habitat and biological communities. Field observations and cross-section surveys indicate the tendency for stabilized stream reaches to become narrower and deeper, as has been documented in previous studies. However, response to bank stabilization appears to be a function of stream size. In general, smaller streams responded more rapidly to stabilization than larger stream reaches. In all cases, channel adjustments continue to be ongoing eight years after the revetments were installed. Four of the revetments sites were selected to assess biological responses to bank stabilization as described in Section E of this document. Biological responses appear to be more rapid than channel responses. The reduction of sediment input into the channel as a result of stabilization was determined to be beneficial to macroinvertebrate communities.

Alternative streambank stabilization techniques, while recently installed and somewhat experimental in the case of gravel bar spawning, appear to provide environmentally friendly approaches to either augment other bioengineering practices or provide substitute methods where cedar revetments are deemed impractical. Gravel bar spawning could potentially provide a means to treat problem banks as they develop and before resource impacts become significant. We will continue to monitor these new approaches and report on their observed benefits and drawbacks in future reports.

ABSTRACT

Significant time and money is being expended by government and private parties to "restore" or "stabilize" streambanks and riparian areas and it is important to assess the actual field results of various techniques to improve future endeavors. This document provides a technically based review of streambank and riparian restoration projects implemented at Buffalo National River (Figure 1) from 1990 – 2000. These efforts incorporated the use of cedar tree revetments and other bioengineering practices along with reforestation of buffers to restore streambank and riparian areas. It also discusses some more recently installed "stabilization" projects. The purpose of this effort is to provide stream managers and specialists with an extensive case-study review. We will discuss: 1.) what the original problems were, 2.) what corrective measures were implemented and why, 3.) what worked and what didn't, 4.) specific factors that appear to influence success and failure, 5.) geomorphic and biotic responses to restoration, and 6.) applicability to other streams and rivers.

OVERVIEW

In 1994, Buffalo National River (BUFF) initiated a three-year streambank stabilization and riparian restoration project funded mainly by the National Park Service's Natural Resources Preservation Program. The purpose of this project was to stabilize eroding streambanks and riparian areas disturbed by agricultural clearing prior to the establishment of the National River in 1972, and areas where agricultural operations are ongoing. BUFF identified 14 streambank restoration sites totaling 5,763 feet in length to be mitigated. We employed cedar revetments and other bioengineering practices wherever practical to mitigate the ongoing disturbance responsible for bank instability. We also identified 29 riparian zones totaling nearly 12 miles in length that needed buffer protection and reforestation. Native seedlings were planted for three consecutive years, covering a total of 60 acres at these 29 sites.

Large restoration efforts taking place on federal lands involve many types of compliance. Significant time and resources were required to develop Corps of Engineers Section 404 permits and cultural resource compliance such as approval by the State Historic Preservation Office. Much time was also dedicated toward archeological investigations which did not always result in clearance where pre-historic sites were identified proximal to restoration areas. Public involvement was also required as some of the concepts we sought to employ were fairly new to the area. After compliance came three years of intense labor. A total of 5,255 feet of cedar revetments were constructed at 12 sites, 8 of which were back-sloped and 4 of which were not back-sloped due to the previously mentioned archeological concerns. Back-sloping and vegetative transplanting alone was used at one additional site. We also established nearly 12 miles of 100-feet wide riparian corridor and replanted these corridors with native seedlings. Six miles of fence was constructed (either alone or cooperatively with park in-holders) along the reestablished riparian corridors to protect stream banks and riparian zones from cattle. Four freeze proof tanks were installed to provide an alternative water source for cattle.

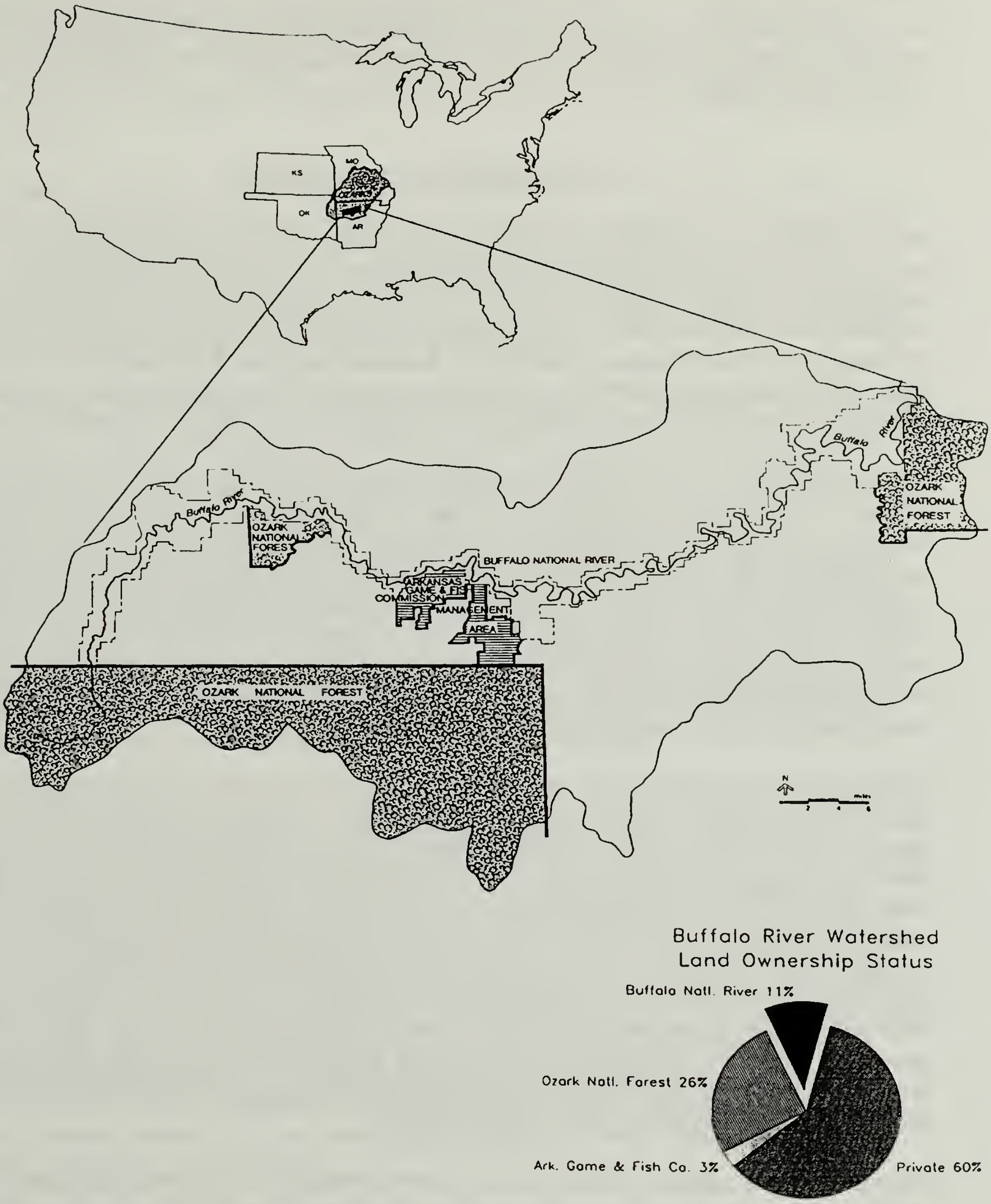


Figure 1: Location of Buffalo National River and watershed land ownership.

Recently, we have preformed willow transplanting at two sites and constructed five rock vanes at three sites where cedar-tree revetments were deemed not to be a practical alternative. Also, these rock vanes appear to be working extremely well and, along with willow transplanting, are discussed in this report.

BACKGROUND DISCUSSION

Buffalo National River (BUFF) is a free-flowing stream in northern Arkansas (Figure 1) famous for its canoeing, fishing, and other recreational activities. The National Park Service's jurisdictional boundary includes a 132-mile river corridor from near the headwaters to the confluence with the White River. BUFF manages eleven percent of the watershed, sharing ownership with Ozark National Forest (26%), Arkansas Game and Fish Commission (3%) and many private land-owners (60%). A myriad of land use activities, mostly related to agriculture, occur in the watershed including wilderness, logging, beef, dairy, swine, and poultry operations.

In some areas the river is confined by bedrock; in others it meanders through alluvial bottoms. It is common for the alluvial floodplains to be farmed up to the present channel banks with little or no buffer strips between cleared ground and the river. This type of farming practice occurs throughout the region and has undoubtedly increased the vulnerability of the river banks to erosion and accelerated channel migration processes within the flood plain (Jacobson and Primm, 1997; McKenney and Jacobson, 1996; Jacobson and Pugh, 1997). It is also probable (Jacobson et al., 1990; Stephenson and Mott, 1992) that past and present land-use practices in the watershed have increased the delivery of sediment to the river and further encouraged the tendency for lateral channel shifts, especially where riparian forests are removed.

Chronically eroding stream banks and channel instability are usually associated with areas where agricultural clearing of riparian vegetation has occurred. Two sites were associated with a 25-year old gravel mining operation where the stream channel had still not recovered. Even with cessation of farming activities, many stream bank erosion sites were experiencing soil loss at such a rapid rate (over 40,000 tons per year at one site) as to preclude natural revegetation processes from stabilizing the bank. In these areas, erosion continues unimpeded and many tons of exposed soil along with cultural, archeological and natural resources are being lost. Once stream bank cutting has begun in a farmed area, the erosive force of the river often undercuts even well established riparian forests down stream from the original site. As a result, the erosion sites grow larger both perpendicular and parallel to stream flow. Additionally, transport of eroded sediment from these banks leads to instability at seemingly unconnected sites further down stream (Leopold et. al., 1964; Leopold, 1994).

Prior to the implementation of the projects reviewed here, former landowners and park managers attempted stream bank stabilization through bank hardening, channelization, and attempts to direct flows away from the bank by removing gravel bars and within-channel vegetation. This management approach often initiated undesired responses in which energy and sediment transport through the altered reaches was changed in a way that encouraged further instability. Additionally, stream habitat and macroinvertebrate communities were virtually destroyed by the within channel bulldozing which accompanied channelization, willow removal, and use of stream substrate to "armor" eroding banks. The intention of the cedar revetments and other bioengineering approaches reviewed here was to apply more environmentally sensitive, longer-lasting, and cost-effective methods of stream stabilization which focused on the ultimate goal of riparian restoration.

The loss of riparian forests contributes to changes in the physical characteristics of stream channels by decreasing the resistance of bank materials resulting in areas of active stream bank erosion. As a result of this erosion, stream channels are shallower and wider, the aesthetic attraction of the corridor is impaired, aquatic habitats are degraded, and water quality is reduced by increased sediment loads and turbidity. The continued loss of riparian forest also degrades habitat for the endangered gray bat and other terrestrial species.

Many of the stream banks cleared for agricultural purposes consist of fine alluvial sediment that becomes highly unstable when riparian vegetation is disturbed. When stabilized by tree roots and other riparian vegetation, these banks produce highly productive aquatic habitat units characterized by lateral pools with stable undercut banks, over-hanging trees, and extensive mats of exposed roots (Rabenni and Jacobson, 1993). Woody vegetation provides other environmental benefits as well, such as restoring a more natural flow of sediment and stream flow energy through the riparian corridor and by providing the hydraulic resistance required to reduce the velocity of flood plain currents and prevent flood plain scour. Streamside trees also provide opportunities for scour pools to form where large rootwads persist in the channel from year-to-year. In reaches where riparian trees are removed, fine sediment has been eroded from the banks and the channel is bordered by the remaining gravel. Vegetative recovery becomes difficult on the remaining course sediment and exposed vertical banks.

The enabling legislation (P.L. 92-237) for BUFF states the park was created "for the purposes of conserving and interpreting an area containing unique scenic and scientific features, and preserving as a free-flowing stream an important segment of the Buffalo River...". The Resource Management Plan (NPS, 1992) approved for BUFF lists water quality as the "Number One natural resource priority for Buffalo National River. Water is the park's major resource and water-based recreation is the major recreational activity. Protection of water quality therefore must be ensured since any type of contamination could lead to serious degradation of not only the water itself, but also have a deleterious effect on other park resources, i.e., wildlife, fisheries and cave life as well as visitor and employee health". The State of Arkansas has recognized the significant value of the Buffalo River through Extraordinary National Resource Waters and Natural and Scenic Waterway designations. Streams with these designations are to be maintained through a variety of means; including protection of in-stream habitat and land management protective of the watershed.

The endangered gray bat forages for insects along the Buffalo River and depends upon protective forest cover along the stream banks. Preservation of riparian travel corridors and aquatic insects are listed as recovery plan objectives for the gray bat.

The six mile long Boxley Valley (Figure 8) is managed as a private use agricultural area and contains significant historic, archeological, and agricultural resources. The entire valley is on the National Register of Historic Sites based on its historic and prehistoric resources. Much of the floodplain within this valley is actively farmed under scenic easements or other exchanges. The narrow river corridor retained by the National Park Service in Boxley Valley is becoming narrower due to ongoing erosion. Continued unmitigated erosion has resulted in conflicts between the National Park Service and private land owners within the valley. Demonstration of the effectiveness of tree revetments as a holistic "working with nature" approach was hoped to sway landowners away from the traditional use of bulldozers to "fix" streams. It was also hoped that the cedar revetment option would spread to tributary landowners within the watershed which would help reduce sediment loads being transported to the river from tributary bank erosion.

In the ten years prior to implementing restoration Buffalo National River monitored 25 erosion sites. The most rapidly eroding cutbank was 2,200 feet long, 10 feet high, and receding at an average rate of 14 feet per year. At that rate, it is estimated that 40,834 tons of alluvial sediment were being added to the river annually from this bank. As part of the initial assessment all banks were categorized according to length, height, rate of erosion, and other factors. The average rate of erosion for the remaining banks is one to three feet per year.

Stream bank inventories of the Buffalo River showed that nine miles of chronically eroding stream banks exist in areas where riparian vegetation has been disturbed. Of these nine miles, five miles of bank, mostly along the upper and middle sections of the river, were deemed suitable for bank stabilization attempts using cedar revetments and riparian revegetation work. The remaining four miles, in the middle and lower portions of the river, were characterized by banks too tall and unstable for successful cedar revetment installation. In the middle and lower river, riparian restoration in buffer areas was the only action taken. The extreme lower river flows through wilderness and is therefore unsuitable for any use of motorized equipment required to perform restoration.

Buffalo National River employees formulated the erosion mitigation alternatives in conjunction with stream management consultants, through inter-agency stream management workshops, and with representatives from the National Park Service's Water Resources Division. We patterned our efforts on work by the Missouri Department of Conservation who installed over 51 revetments in the 1980s. They also carefully monitored these projects and completed a status report (Fantz et. al., 1993) which documented a success rate of ninety percent. Failures were attributable to preventable errors, such as 1) failure to properly secure trees to anchors, 2) trees too small, 3) pockets of very loose sand in the bank toe which didn't hold anchors. The authors also reported that there were no adverse side effects when the structures failed, and the needed repairs were relatively minor in most instances.

An in-depth analysis reported by Gough (1990) used cross-section transects and fish community data to understand stream fish habitat response to tree revetment installation. In general, cross sections in treated reaches became narrower and deeper as a response to restoration. Percent cover and current velocity diversity increased. Presence of larger game fish also increased and low-flow pool volumes nearly doubled at some transect points. Gough also noted that as riparian trees regrow and bars become stable, they tend to store sediment instead of generating it.

Based on efforts at BUFF and in other areas within the physiographic setting of the Ozarks, the most promising, practical, and cost effective method for stream bank erosion control and eventual riparian restoration employs cedar tree revetments for stream bank stabilization. Cedar revetments are used extensively in the alluvial streams of the area where a return to natural conditions is desired. The Missouri Department of Conservation has been successfully applying cedar revetments to erosion problems for over a decade (MDC, 1986). Tree revetments employ large cedar trees, which grow in abundance in successional fields, positioned at the base of the eroding bank and anchored in place in a continuous shingle-structured chain. The angle of the bank is back-sloped to a 1:1 angle prior to constructing the revetment. If an archeological site was found near the bank the bank was not disturbed. Seedlings of riparian trees such as walnut, oak, ash, sweet gum, etc., are planted on the cut bank and in the riparian buffer behind the bank. Pumps were used to water the newly planted riparian areas in an attempt to insure good survival and growth of seedlings and volunteer species.

The underlying principal of a cedar revetment is to slow the force of the eroding waters with the tree branches and promote deposition of sediment within the branches. This newly deposited sediment acts as a seed bed for the growth of further vegetation which continues to stabilize the revetment. The revetment also provides immediate benefits to aquatic habitat by providing cover and decreasing sediment loading. Behind the revetment, the planted river cane and seedlings grow, take root, and begin to bind the soil. The objective is for the revetment to protect the bank long enough for the riparian trees, river cane, willows, transplanted native vegetation, and volunteers to achieve a sufficient size and root structure. This will in time restore the natural level of stability inherent in a well functioning riparian area. Management actions were undertaken at each of the proposed revetment sites to provide a minimum 100 feet corridor between ongoing agricultural operations and the stream.

Our restoration strategy incorporated a holistic view of streams and employed natural materials and natural processes to restore the dynamic equilibrium between the river channel and its banks. Two plants used in our bioengineering were native river cane (*Arundinaria gigantea,* a type of bamboo) and willow (*Salix sp).* River cane was transplanted from floodplain areas, away from the river by digging out the rhizomes and planting them in trenches running at an angle up the bank. Traditional willow staking was also attempted but always failed. Whole willow transplanting, however, was very successful and is discussed in detail in the Alternative Approaches section. We did not attempt to incorporate elements of "natural channel design" (Rosgen, 1994) into our restoration scheme. In other words, we did not use heavy equipment to manipulate existing channel dimensions to achieve bankfull parameters (such as width, depth, sinuosity, etc.) associated with naturally stable reaches. Rather, our efforts might better be described as a "band-aid" approach. It was our belief, based on the importance of riparian vegetation to Ozark stream stability (McKenney and Jacobson, 1995, Jacobson and Pugh, 1994), that with the restoration of bank stability the channel would adjust itself to a more stable profile. However, in our monitoring we have focused on important bankfull measures to determine if self-adjustments are occurring.

We believe our implementation strategy was the most appropriate for free-flowing streams and is in keeping with the management objectives for the river and the Boxley Valley National Historic District as stated in the Master Plan (1977) and the Boxley Land Use Plan (1985). The ability to protect park resources to the fullest possible extent while providing for the continued use of adjacent lands is a common need experienced by many National Rivers and Wild and Scenic Rivers within the Park System. Successful corridor restoration at BUFF provides a positive model for other areas, although the exact methods and materials used in different physiographic regions are dependent on site specific parameters.

EROSION PROCESSES

This section presents a detailed explanation of the various erosional processes observed along the Buffalo River and its tributaries. This will provide the reader with a reasonable understanding of why a particular restoration strategy was developed for each of the erosion sites along the Buffalo River. The management schemes employed were designed with each of these erosion processes in mind.

Slope Failure (Slumping and Block Failure):

The most common erosion process acting on the Buffalo River's banks is slope failure. Although slumping is the dominant process on the majority of eroding banks, each process described in this section is active to some degree at all sites. Figure 2, shows a schematic representation of slumping, which is also called rotational failure. Slumping typically occurs when floodwaters saturate the bank to near the bank-full depth or beyond. When the flood waters recede, the weight of the water trapped in the near bank floodplain (pore saturation), along with the bank weakening resulting from the saturation and scour, combine to produce stress forces which exceed the cohesive forces within the bank and the bank slumps. Many tons of soil can be moved from the bank into the channel when this slippage occurs.

Slope failure on stream banks is greatly influenced by the density, width, and integrity of the riparian forest on and adjacent to the bank. As shown in Figure 2, the scarp line typically extends some distance beyond the edge of the stream bank and into the floodplain. The distance the scarp extends into the floodplain is a function of the bank slope and height. Figure 3 shows two scenarios for a stream bank under pore saturated conditions. The bank height and slope are the same in the two drawings. In Figure 3a, the flood plain forest has been removed. In this case, the slump line extends beyond the zone where the binding structure of roots can have any effect in preventing slumping.

In Figure 3b, the interlocking roots of the flood plain forest help to prevent the scarp line from developing by providing lateral binding across the potential scarp line. In the event slumping does occur, the interlocked roots tend to prevent the failure from becoming a catastrophic process. The floodplain forest also prevents the domino effect of slump scarps which migrate up and down the disturbed reach. This chain reaction is often observed in areas lacking a floodplain forest. Thus it is very important to maintain a well vegetated riparian corridor on <u>and behind</u>

stream banks.

Rotational failure is also greatly influenced by the alluvial sediments which make up banks. It is most commonly seen in banks that have differing layers of sediment. Banks in which an impervious layer of well-consolidated silt or clay lies within the lower portion of the bank seem to be the most susceptible. These layers prevent drainage of water from bank sediments and may also act as lubricating layers on which the slump slides.

On clay and silt rich stream banks, block failure is commonly seen. Figure 4 shows the profile of a stream bank affected by block failure. Scour and removal of vegetation at the toe of the bank is instrumental in initiating and perpetuating this type of failure. Generally, these banks do not have course armoring materials (usually cobbles) at their toes. As the unprotected bank toe is scoured away, the bank material above it is left unsupported. Unlike rotational failure, block failure occurs along a vertical line as a "block" of bank material slides down into the channel and is carried away by the current.

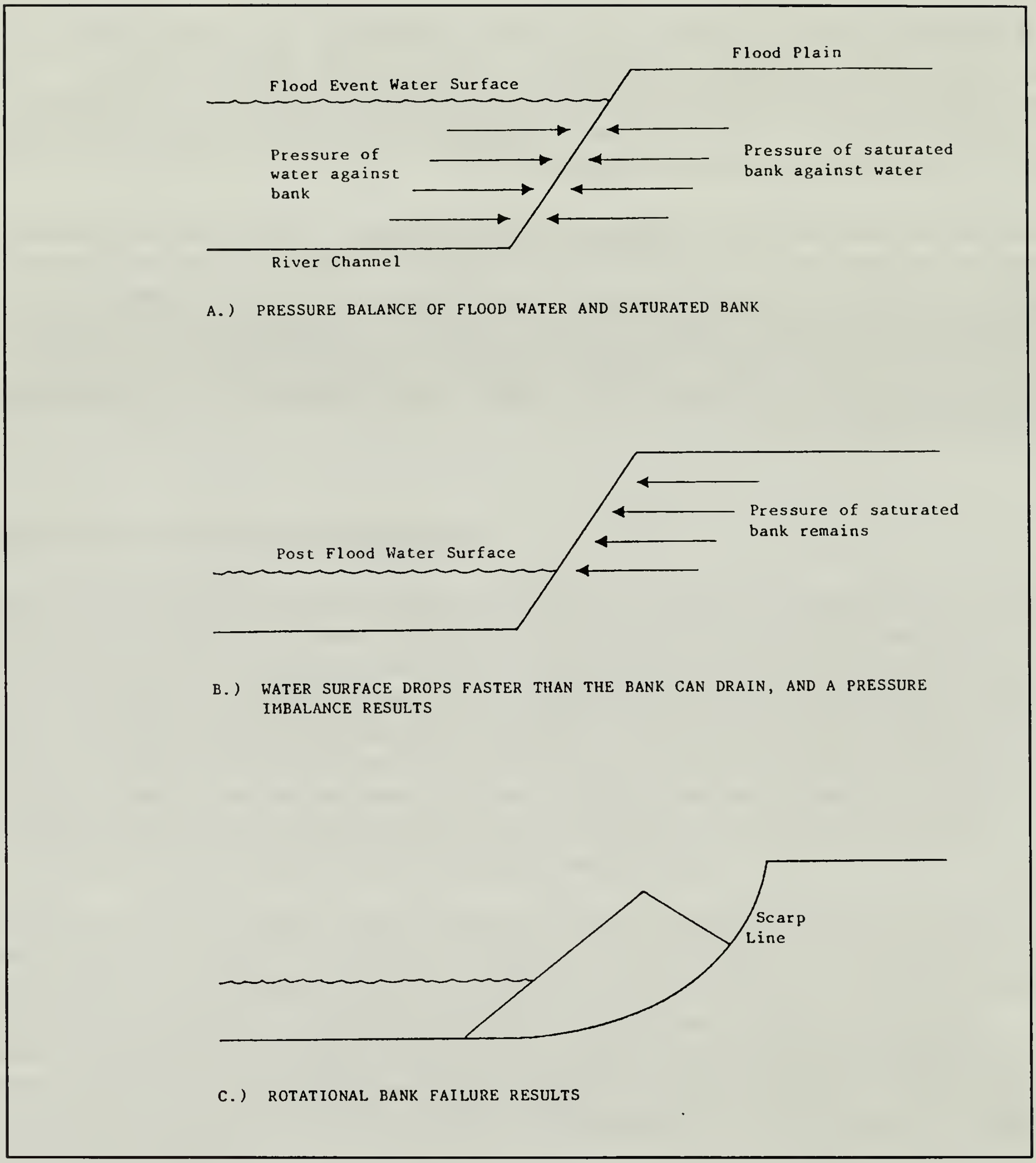
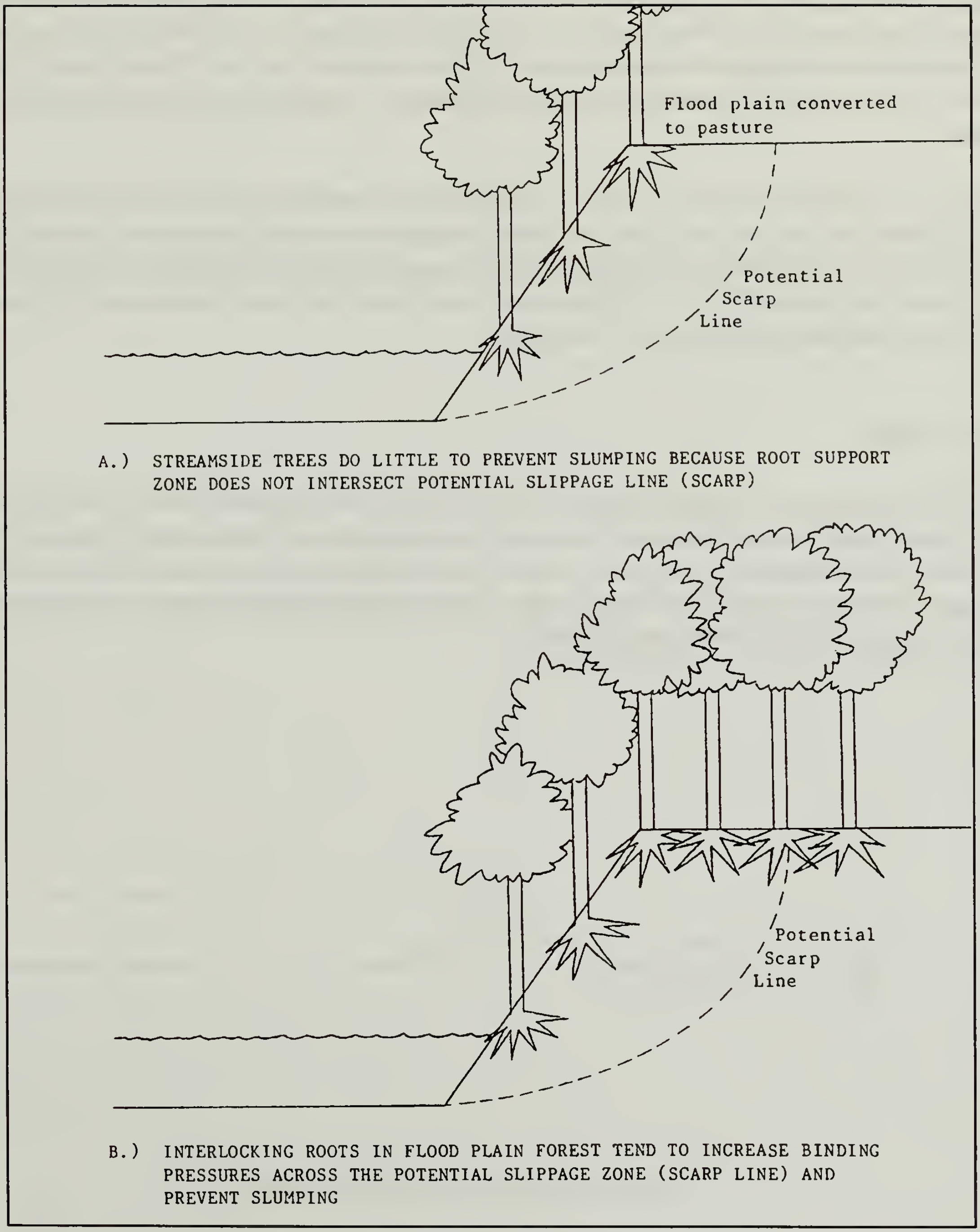


Figure 2: Engineering sketch of rotational failure.



A.) STREAMSIDE TREES DO LITTLE TO PREVENT SLUMPING BECAUSE ROOT SUPPORT ZONE DOES NOT INTERSECT POTENTIAL SLIPPAGE LINE (SCARP)

B.) INTERLOCKING ROOTS IN FLOOD PLAIN FOREST TEND TO INCREASE BINDING PRESSURES ACROSS THE POTENTIAL SLIPPAGE ZONE (SCARP LINE) AND PREVENT SLUMPING

Figure 3: Two scenarios for slope failure.

Scour:

Scour is more significant on stream reaches where the radius of curvature is small, but it affects all banks where stream-side vegetation has been removed. Scour often increases the bank slope and thus increases the forces of stress which promote slumping. Again, stream side vegetation is the most effective way to prevent scour in alluvial stream channels. Besides providing roots which increase the strength of bank materials, the above ground portion of trees greatly dissipate the erosive force of flowing water by increasing hydraulic roughness and decreasing stream-side velocity.

Scour is also noted where over-bank flow occurs in areas lacking riparian cover. In these cases, acres of floodplain soil can be "blown out" from pasture areas along the stream corridor when high velocity flood waters move into agricultural areas lacking the hydraulic roughness and soil binding provided by buffer trees. Riparian and flood plain trees slow the erosional forces of flood waters and add stability to the flood plain.

Sheet and Rill:

Sheet and rill erosion are usually thought of in association with upland erosion, but they are also active stream bank erosion processes especially in association with taller, sandy banks which have experienced slumping in the past. Where the flood plain slopes toward the stream channel, overland flow can transport water to the edge of the agricultural field where it pours off and erodes the naked bank as sketched in Figure 5.

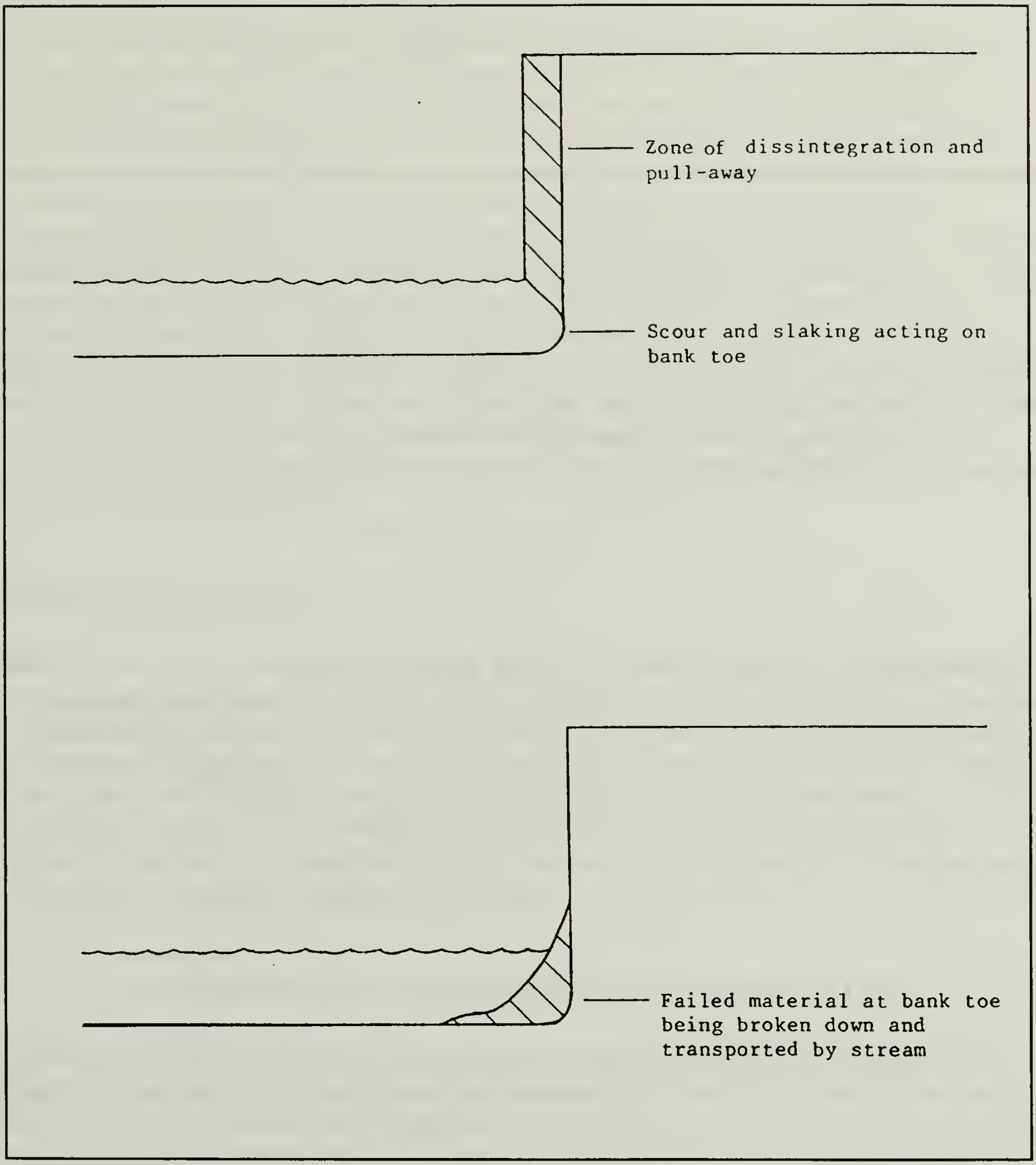


Figure 4: Processes involved in block failure.

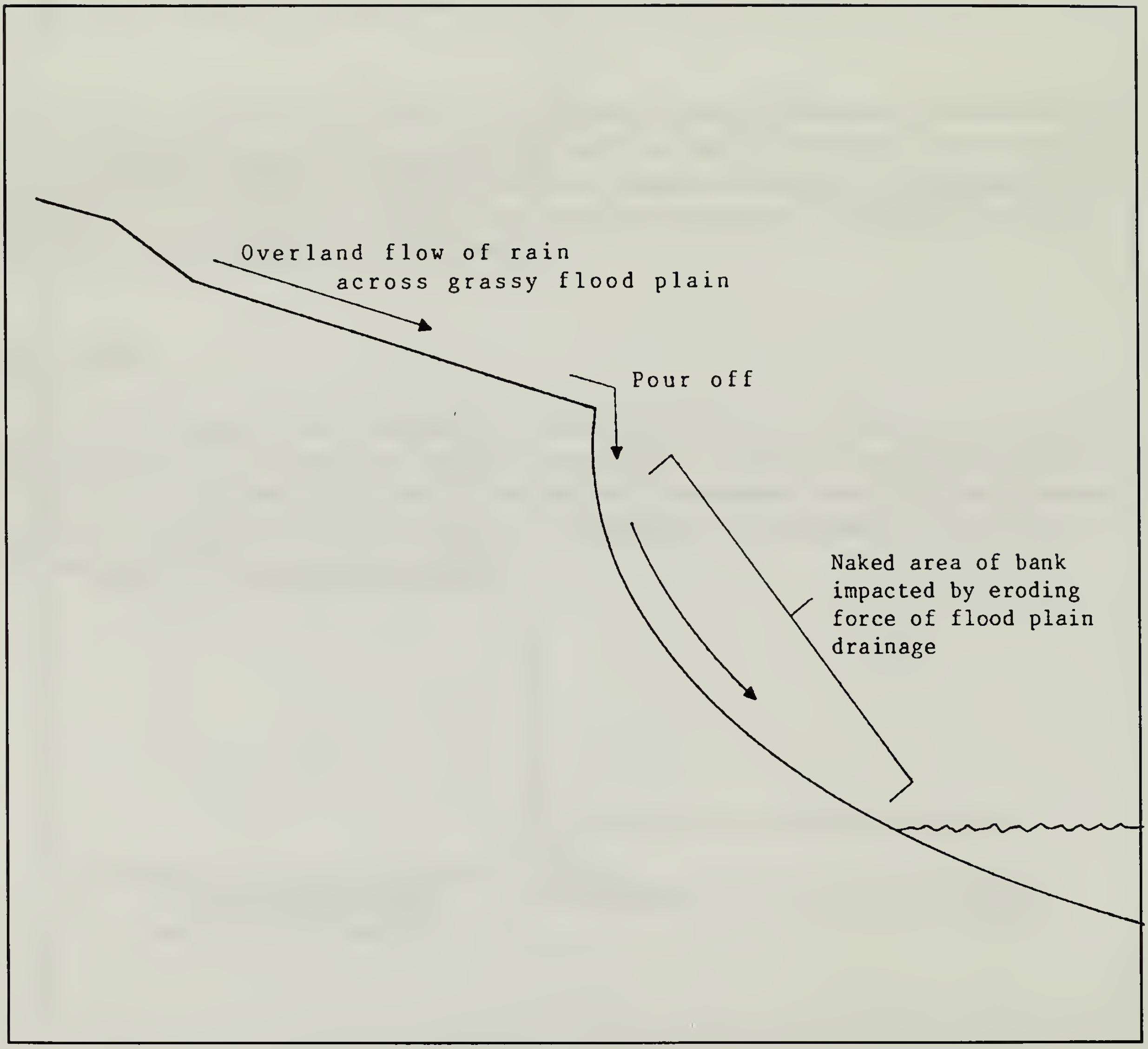


Figure 5: Sheet and rill erosion on unvegetated erosion banks.

RIPARIAN FOREST DESTRUCTION

The destruction of riparian forests for agriculture is an aggravating factor for all sites included in this report. In some cases, the stream-side trees were not actively removed, but channel modification or other natural or human activity caused the thin corridor to be breached and destroyed. Corridors should be wide enough to accommodate natural river meandering and increased stream power due to human modification of other reaches and within the watershed. In all corridors along the Buffalo River administered directly by the National Park Service, minimum 100 foot buffers were reestablished through this project. On tributaries, corridors were reestablished and maintained to between 50 and 100 feet. In private use areas (Boxley Valley), corridors retained in NPS ownership are typically less than 100 feet. Corridors in private use areas were also restored to floodplain forest and maintained to the fullest extent possible. However, Richland Valley represents a unique area because the nearly 4 mile section of Richland Creek inside the boundaries of Buffalo National River was returned to private ownership without the benefit of any federal protection clauses within the exchange which provide riparian protection. Other sites needing restoration which were not possible included several Use and Occupancy tracts along the river.

Propagation Zone Concepts:

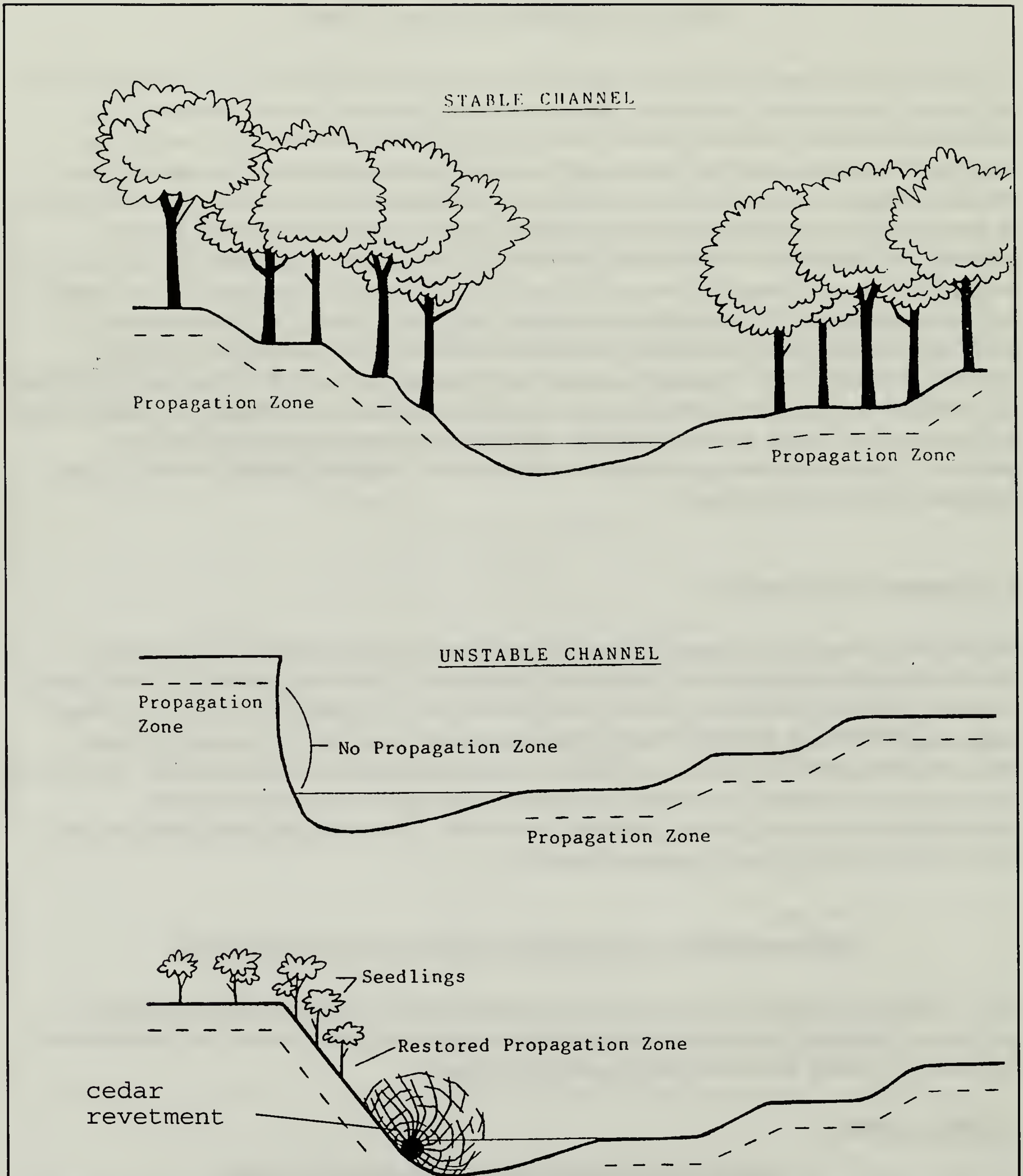
Streambank revegetation approaches depend greatly on an understanding of the interaction between channel morphology and stream-side vegetation. Plants can grow only in certain parts of a stream channel. These areas, called propagation zones, are defined in Figure 6. Eroding banks, especially those in which block failure has occurred, tend not to revegetate naturally because plants cannot take root on the vertical banks which result from this process. Thus part of the revegetation approach is to backslope the bank to present a more gentle slope for revegetation, and protect the bank with a tree revetment. Given adequate soil conditions and a more moderate slope, plant propagation can occur.

GEOMORPHIC CATEGORIZATION OF EROSION SITES

The banks to be mitigated through this project were categorized based on their geomorphic properties. Grouping sites helps explain both the erosion processes occurring at these sites and the severity to which erosion can be expected to continue.

Confluence Sites:

Confluence sites are eroding banks along tributary reaches within the Buffalo River's floodplain. As tributaries enter the Buffalo's floodplain, the larger hydraulic forces of the river begin to influence and even override channel morphology and fluvial processes within the smaller confluencing stream. As a result, bank height in the lower reaches of these tributaries greatly increases to eventually match that of the Buffalo. Another factor-affecting confluence sites is



Figute 6: Propagation zones along Buffalo river.

that sediment transport processes are chaotically influenced. During localized rainstorms in the tributary watershed, there is only slight influence of sediment transport within the lower reaches. If the Buffalo is flooding, however, transport of all but the finest particles will cease as the tributary comes under the influence of backwater from the Buffalo River. Thus, depending on how the hydrographs of the two channels coincide, sediment slugs will be deposited at different times and places along the tributary within the zone of backwater influence.

Generally, tributaries show changes in cross-sectional morphology and planform as they enter the Buffalo River's floodplain. Meander amplitude increases and, in many cases, tributaries form small active channel shelves within the high banks of confluence reaches. As tributary channels near the river, it is common to see deltaic forms with multiple channels, bars, and channel shelves, which are generally stable. The main tributary channel, however, usually lies along a high cutbank, the top of which coincides with the general elevation of the Buffalo River's floodplain. These high cutbanks are only marginally stable because the root zone may not extend to the bank toe. Tall banks are thus particularly prone to become unstable when riparian vegetation is disturbed. Because confluence areas are usually in agricultural use zones, the woody corridor is likely to have been destroyed or be too thin to prevent slumping.

Channel Modification Sites:

Channel modification sites have been modified by straightening, gravel mining, or by pushing bed and bar materials against cutbanks with a bulldozer. These practices usually follow riparian corridor removal, which probably affected the stability of the bank in a negative way to begin with. Although pushing gravel and cobbles against cutbanks has, in some cases, stabilized bends, this practice is done at a cost. Channel modification can destabilize reaches above the treated section by locally increasing channel slope. Bank erosion, usually resulting in the destruction of healthy riparian corridors, occurs downstream of the reach because velocities increase as a result of straightening or a decrease in roughness. Finally, the treated section is permanently altered if the materials pushed onto the bank cannot be moved by the present flow regime.

Overbank Scour Sites:

Overbank scour sites form only in areas where the riparian corridor has been eliminated and where the river can "short cut" across a floodplain. The Sheldon Branch field erosion site is a classic example of this process. The map in Figure 7 shows the planview form representation of the Sheldon Branch Field. When flood waters top an already eroding bank on the upstream end of the floodplain, the high velocity waters encounter nothing to slow them down or to stabilize and bind the flood plain soils. The turbulence generated at the contact between the floodplain and the streambank tears massive amounts of soil from the top of the bank, often depositing hundreds of cubic yards of sediment further out in the floodplain. Where this overbank flow re-enters the river, channel erosion also takes place, although it generally does not appear to be as severe as along upstream banks.

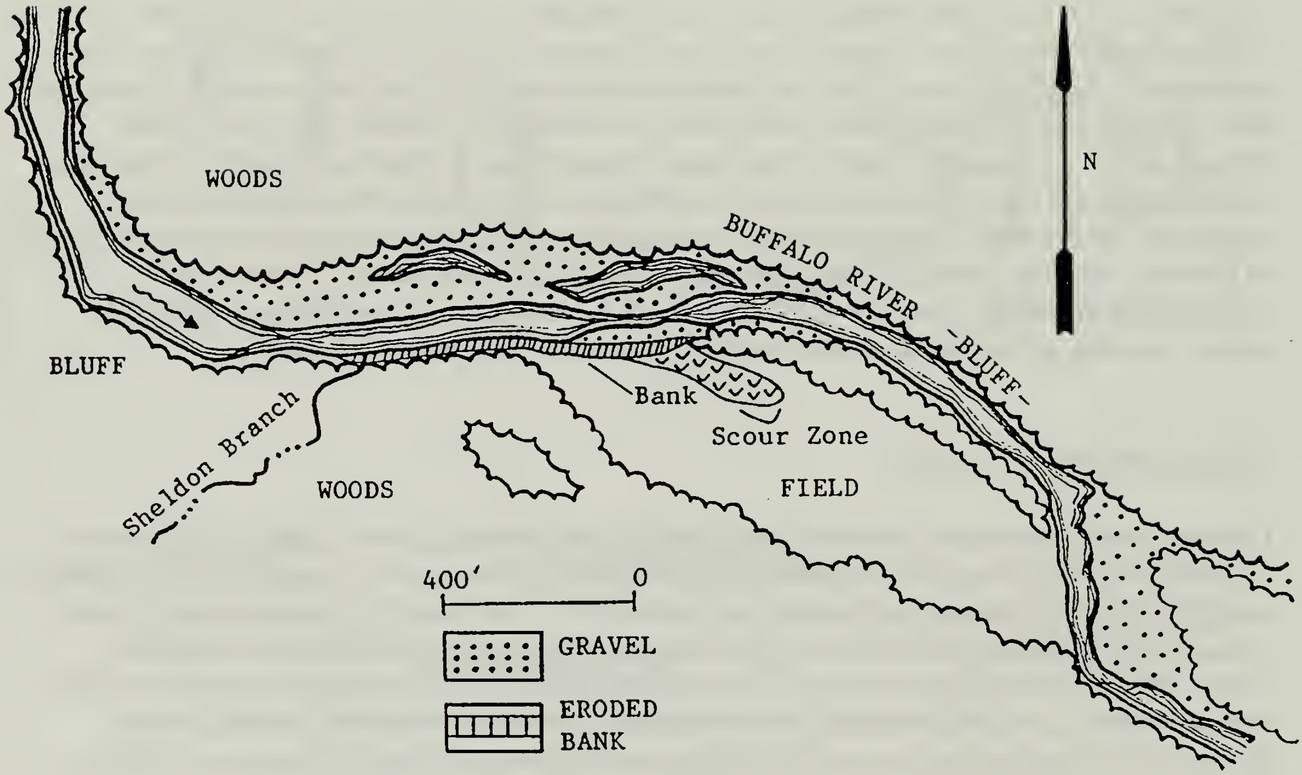


Figure 7: The Sheldon Branch Site as an example of overbank scour.

Valley Crossover Sites/Disturbance Zones:

Almost all river systems must periodically adjust to perturbations from large floods and/or land use and other factors. These adjustments are manifested by changes in channel cross-sectional shape, slope, and planform and generally occur at the weakest points in the fluvial system. Within the Buffalo River basin, most stream reaches are resistant to change in one or more dimensions. Vertical adjustments are limited by bedrock or beds covered by coarse particles that are relatively difficult to move as compared to the flood plain soils in unvegetated banks. Many reaches within the Buffalo River basin are laterally controlled by bedrock bluffs. Thus, several of the laterally unstable sites within the basin occur where the river crosses from bluff to bluff.

Even when valley crossover reaches are well-vegetated, they are much less resistant to erosion than the adjacent bedrock-controlled reaches. Also, because these river sections lie in areas favorable to agricultural use, their riparian buffers are much more likely to be disturbed, reduced to thin strips, or destroyed. Often, valley crossover reaches contain disturbance zones. Jacobson (1995) divides Ozark stream reaches into two dominant categories, stable reaches and disturbance reaches. Stable reaches are characterized by low sinuosity, nearly trapezoidal cross-section, and little lateral erosion. Disturbance reaches are characterized by rapid lateral channel migration of as much as 250 meters in 50 years. Disturbance zones were determined to be a natural feature of Ozark streams. As stated by Jacobson and Bobbitt, 1999, "channel patterns of Ozark streams are characterized by juxtaposed stable and disturbance reaches." Stable reaches are often located adjacent to a valley wall and tend to be long and straight, with low rates of channel migration (<0.1 meters per year). Disturbance reaches are characterized by more frequent channel migrations (>0.5 meters per year), and ongoing sedimentation and erosion (McKinney et al., 1995). Jacobson and colleagues research tells us that, among other things, it is very important to be able to recognize naturally occurring disturbance reaches. In disturbance reaches it may be very hard to restore a stable stream because stability is not a natural tendency of the stream in these reaches. Rather, it is critical to manage for healthy riparian and floodplain vegetation in these areas, and to do so with as wide a buffer as possible. This management approach gives the stream room to expend its erosive energy and process the sediment load being routed down the channel. A case in point is the Ferguson site, which is discussed later in this document.

Massive Slumping and Block Failure Sites:

Some eroding banks have no obvious geomorphic predisposition to be unstable. Mass failure sites are usually associated with agricultural clearing of the flood plain up to the edge of the stream bank. Once these banks slump the instability can be propagated both up and down stream, but typically they propagate in the downstream direction and result in instability over long reaches. These reaches were probably stable for many centuries before the clearing and other impacts to the riparian zone occurred as evidenced by the artifacts now eroding out of some of the banks.

HYDROLOGY

Every stream has a unique hydrologic regime. Some streams are slow and sluggish, others are fast and clear. Some streams are dominated by groundwater inputs, others by surface runoff. Some streams are little afffected by precipitation events, others are flashy. The Buffalo River is fast and clear, its channel is formed by surface runoff events, and these events can be tremendously flashy. These characteristics make a the Buffalo River resilient, but at the same time challenging to restore once the stability threshold has been crossed. This section is included so that the reader will have a context to compare with other streams to.

The longest recording flow gauge on the Buffalo River is located near St. Joe, Arkansas,in the middle portion of the river and has a drainage area of 829 mi^2. The record low-flow at this site was 6 cfs in 1957 (about 3 feet of stage). The record high flow at this same site was 158,000 cfs in 1982 (about 55 feet of stage). The U.S. Geological Survey estimated the recurrence interval for the 1982 flood at 65 years. Average flow velocities during this flood were estimated to exceed 14 feet per second.

Since the first revetment was constructed in 1994, they have been subjected to several flood events. Figure 8 shows the results of a flood which passed through the Buffalo River system on September 26th and 27th, 1996. The flood resulted from about five inches of rain falling over about a 12 hour period. At the uppermost site, Ponca (see Figure 9 for reference), the rate of rise exceeded two feet per hour for 8 hours. In June of 2000, an even larger and flashier flood was recorded. In fact, at Ponca the 2000 flood had a peak stage only one inch lower than the 1982 flood of record, and at one point rose 8 feet in one hour.

In summary, the Buffalo River is one of the flashiest free-flowing large river systems remaining in the eastern United States. If the bank stabilization practices reviewed here worked on this stream system, they should work in other areas. However, the overall lessons discussed in this document and the considerations presented in the Assessment Questionnaire must also be factored into site-specific restoration strategies before a decision can be made regarding if cedar revetments are appropriate on a particular system or reach.

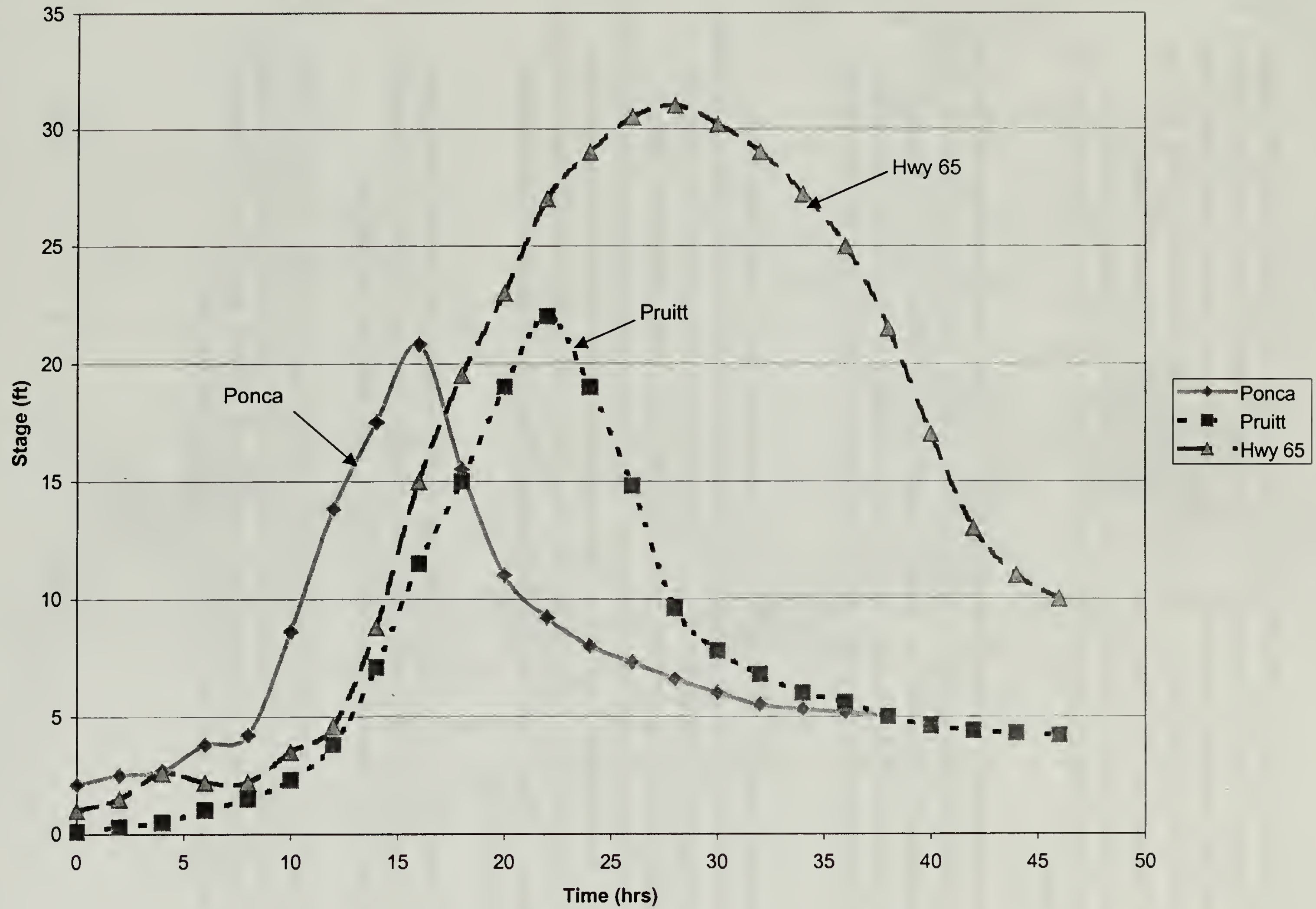


Figure 8: Buffalo River hydrograph at three sites during September 26 and 27, 1996.

MITIGATION STRATEGY

Sites addressed by this program were separated into stream bank stabilization sites and riparian restoration sites. However, riparian restoration was also performed at stream bank stabilization sites. Table 1 (page 90) lists the riparian areas replanted and Figure 9 shows where these areas are located relative to the National River. Riparian plantings were performed on an 8 X 8 foot grid using native tree species. Seedlings were procured through the Arkansas Forestry Commission nursery and planted using contract labor supervised by National Park Service employees. Work to plant the seedlings commenced in February of 1995 and continued for the following three years.

Section A of this assessment focuses on actions taken along stream banks needing stabilization before a healthy riparian corridor could be re-established. Table 1 (page 90) and Figure 8 lists the revetment areas and shows where they are located relative to the National River. As stated earlier, the primary purpose of this project was to restore the natural riparian and stream side vegetation and achieve natural geomorphic conditions within the stream channel and adjacent flood plain.

Tree revetments present many advantages over more traditional "hard" methods of bank stabilization and restoration. The most significant difference is that tree revetments act to reduce flood water energy instead of simply focusing it or transferring it downstream. The extreme hydraulic roughness and resulting decrease in velocity caused by cedar revetments tends to promote sediment deposition within the revetment. This deposited sediment forms an excellent rooting medium for the propagation of stream-side vegetation. Tree revetments also promote vegetation growth by shading the bank surface and improving soil moisture conditions during the warm growing season. Along with deposited sediments, the seeds of riparian tree species are deposited and may take root.

Tree revetments also reduce high-velocity overbank flows, and thus may prevent flood plain scour as well. By absorbing energy within the reveted length, they can prevent the downstream transfer of energy that often leads to erosion below hard structures such as rip rap.

Finally, tree revetments are much more aesthetically pleasing than most other bank restoration methods. They tend to appear more natural and disappear over time as self-maintaining woody vegetation grows on the site and gradually takes over the role of bank protection. After one growing season most revetments went unnoticed by persons floating the river.

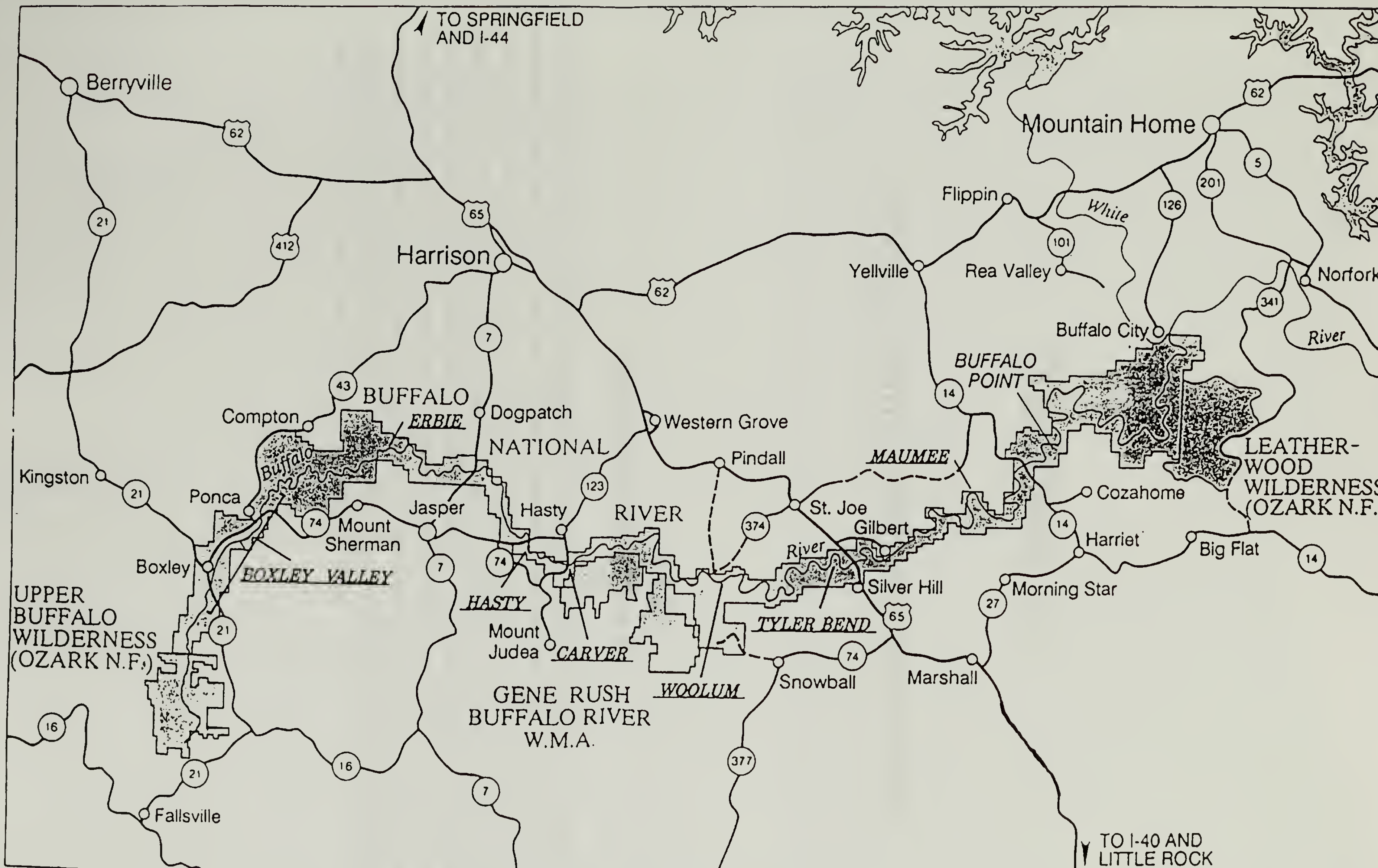


Figure 9:Buffalo River regional map.

Section A

Stream Bank Stabilization Sites

Introduction to Section A

The following section reviews each section of streambank stabilized with one or more methods between 1994 and 1996. Fourteen sites are discussed in order from the upper-most site to the site furthest down river (covering a distance of 92 river miles). The discussion of each site begins with a pre-project site description that summarizes the condition of the bank , channel, and riparian zone prior to stabilization. Next is a project description section which details what was done to stabilize and restore the streambank and riparian zone and why. Finally, we present a summary of project results section in which we describe how the bank and channel have responded to the stabilization efforts. This section is often divided in upper, middle and lower thirds of the bank where these thirds are markedly different.

Wilderness Boundary

River Mile: 132.5
Site Type: Channel Disturbance
Bank Height: 10 feet
Bank Length: 525 feet
Technique: Willow staking, riparian restoration and site monitoring

Pre-Project Site Description

This site is located in the upper reaches of the Buffalo River. A reach about 3/4 mile long, which includes the area to be restored, was used as a borrow area by local contractors for the Arkansas Highway Department in the late 1960's for the construction of Hwy 21. Excavations can be seen in the 1972 aerial photo series. As a result of this work, instability extends upstream from the agricultural use area and into the currently designated Upper Buffalo Wilderness. The channel is unusually wide as a result the mining and later instability caused by mining. The bar opposite the bank has rebuilt to some extent and supports a dense stand of willows. The lower 1/3 of the bank is composed of gravel and cobble in a sand matrix, the upper bank is sandy clay. Bed material is primarily cobble and boulders, which may be a result of the sorting process used during mining (i.e. cobble-sized material may have been left on site). Bedrock exposure is visible above and below the bank. Any real control over this site has been offset by the channel disturbance.

A lens of rocks, cobbles, and boulders in a clay-loam matrix at the base, with an overlying layer of clayey loam characterizes the eroding bank. The mixture appears to provide stability with regard to slumping (i.e. slumping does not appear to be a major problem along this bank). The eroding bank at the project area is 10 feet high and 525 feet long. Most of the current erosion is taking place as scour and slaking at the toe of the bank and concomitant block failure. Because the bank is vertical and the base is below the root zone even where trees are present, erosion is continuing. In-channel bar stabilization by willows and other vegetation is also forcing the current toward this bank. There is a rapid succession of willows moving into the opposite side of the channel. The period of growth for these willows is less than 25 years, or the time since the borrow work was completed. The bank is eroding approximately 1 feet per year based on ground monitoring from 1985 through 1992. This indicates that the majority of the erosion taking place in this area probably occurred in the decade following the borrow pit disturbance, and that the rate of erosion is declining. Although the eroding bank is vertical for several hundred feet, it does not appear to be moving very rapidly (based on row of transplanted saplings relative to cut-bank). There is also a row of willows forming at the base indicating some degree of toe stability. This is generally considered a good sign, but bears monitoring to determine if erosion continues behind these willows as they form. A 10 feet thick area of trees (one row) is visible on the 1972 aerial photographs. Some thin sections of the corridor are attempting to revegetate naturally


Photo 1: Lower half of the Wilderness Boundary Site (1994).


Photo 2: Lower half of the Wilderness Boundary Site (2000).

Project Description

A cedar revetment was not constructed at this site because the cobble lag at the toe of the bank would make driving of anchors very difficult. The riparian area was already beginning to revegetate as well and planting of saplings and seedlings has already been done in this area. Monitoring work indicates that the bank has receded little in the past nine years and vegetation is taking hold at the toe of the bank, which also indicates stability. Actions to cut the bank back or use heavy equipment on the top of the bank would probably have done more harm then good due to damaging the woody vegetation trying to take hold on this bank. Cobble bars are also beginning to form in the channel near the base of the bank and are revegetating. The most important factor leading to stabilization of this bank is that the channel disturbance ceased. Park staff back-sloped a 50 foot portion of this bank in the late 1980s and drove numerous willow stakes into the back-sloped region. The willow stakes died, as can be seen in Photo 1. Several other willow staking attempts were made at various locations throughout the length of the river and at various elevations relative to the channel. In our experience willow staking does not work here because the stakes do not seem to be able to tolerate the radical changes in stage experienced by the river over the course of a given growing season. However, we have found a method to use willows for bioengineering which is discussed later in the willow transplanting section.

Summary of Project Results

This site is still eroding, but appears to be slowly stabilizing. There are sycamores and willows populating the bank along the toe of the slope. The downstream portion of the site has eroded an additional 15 feet. The thalweg appears to be moving out away from the bank. There is also a dense growth of annual vegetation covering the top of the bank. This site provides an example that the most important factor in restoration is removal of the disturbance. Often given enough time, the reach can stabilize on its own. However, it should be noted that the in-stream gravel mining occurred over 30 years ago at this site, but recovery, while ongoing, is far from complete.

Luallen

River Mile: 131.6
Site Type Channel Disturbance
Bank Height: 9 feet
Bank Width: 450 feet
Technique: Cedar tree revetment and riparian reforestation.

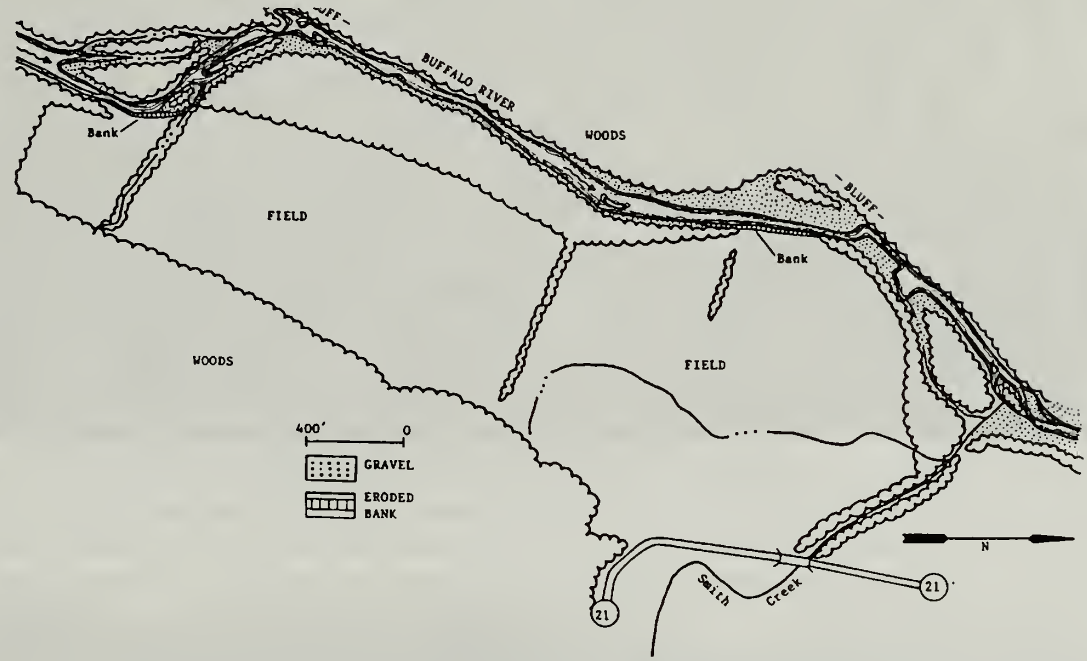


Figure 10: Planform sketch of the Wilderness Boundary and Luallen Sites

Pre-Project Site Description

This site is located in the upper reaches of the Buffalo River. A reach about 3/4 mile long, which includes the Luallen site, was used as a borrow area by Arkansas Highway Department contractors in the late 1960's for the construction of Hwy 21. Excavations can be seen in the 1972 aerial photo series. This site appears to coincide with the lower limits of the borrow pit activities. The channel shape is similar to the Wilderness Boundary Site, over-widened by past sand and gravel mining. There is a well-vegetated lateral bar on the opposite bank. The bank toe is composed of coarse cobble lag deposits left after bank erosion or during the borrow pit process or pushed up during some later bank armoring attempt. Upper bank is silty sand. There is bedrock lateral control present on the river left immediately downstream. Cobble bed appears to control vertical channel movement. In 1994 a revetment was installed at the upper edge of the cobble extending to about 3 feet below the top of the bank. Bank height is 9 feet, reveted reach is 450 feet long. The dominant erosion mechanism is scour on the upper 3/4 of the bank during flooding followed by removal of coarser material as the thalweg shifts toward the eroding bank. The rate of erosion determined from 1972 - 1992 aerial photographs was 2.5 feet per year. Ground monitoring from 1985 - 1991 indicated an erosion rate approaching 0.5 feet per year. As in the Wilderness Boundary disturbance site, it appears that the rate of erosion is slowing at this site. A 10 feet thick area of trees (one row) is visible on the 1972 aerial photographs. Good buffers are in place above and below this site although they are too thin.

Photo 3: View upstream of Luallen Site (1994).

Photo 4: View upstream of Luallen Site (2001).

Project Description

A cedar revetment was constructed at this site and was maintained as part of this project. River cane and saplings were transplanted along the bank and riparian buffer. Ten willow stakes were driven into the bank at various elevations as an experimental project in the winter of 1994. These stakes were monitored throughout the summer and subsequent willow stake planting at this site was not undertaken due to the results of this experiment. Seedling planting had already been undertaken in the 100 feet wide corridor associated with this bank. In 1995, 5 trees were added to the revetment at this site.

Summary of project results

Overall Summary – The revetment and experimental willow staking efforts here have partially failed. It was discovered in part as a result of this project, that willow transplanting rather than willow staking was more successful. The lower portion of the bank has eroded an additional 25 feet since 1994. The riparian corridor has a good growth of mixed hardwood, but has been cut back to only 75 feet in width in some places. The channel here does appear to be attempting to stabilize. The toe of the upstream 250 feet of the site has numerous sycamore trees emerging from it. The lower 200 feet of the revetment was rebuilt in December of 2000 (as can be seen in photo 4) and willows were transplanted rather than staked. The dominant reason for failure, in the lower 200 feet, resulted from a combination of factors. The extremely high magnitude flash floods that come out of the Boston Mountains radically scour the bank. Also, the overwidening and other geomorphic alterations caused by the gravel mining have affected pool – riffle spacing, sediment transport, and flood plain interactions, among others. One result of this is acres of even-aged willow propagation within the channel opposite the erosion bank. The willows are continually encroaching on the channel and forcing flow against the revetment. Our latest strategy combines the replacement of the cedar revetment with whole willow transplanting, or moving willows roots and all, from the river left edge of channel to the river right edge of channel in front of the revetment. In essence we are fighting willows with willows (see willow section for further discussion). While we have had good success with willow transplanting at other sites, this site represents additional challenges and we can not yet say if the transplanted willows will be able to offset the encroachment of volunteer willows. Because of the radical alteration of this ¾ mile long reach where the gravel mining took place, it may be appropriate to consider using natural channel design techniques which restore bank-full fluvial geomorphic channel parameters if this site continues to show less than desirable response to our current treatments. We will continue to monitor this site and repair if necessary.

Upper Third – The upper third of the bank is stable and numerous sycamores and a few willows growing along the toe of the slope. There is very little vegetation growing on the face of the upper bank.

Middle Third – The upper half of the middle third is stable with sparse annual vegetation growing on the bank face. There are juvenile sycamores growing along the toe of the slope. The lower half is continuing to erode and supports no vegetation.

Lower Third – The lower third is continuing to erode and supports no vegetation. The bank here has eroded an additional 20 feet or so. The revetment was rebuilt in this lower section in 2000 and willow transplanting is being used to protect this zone

Beech Creek

River Mile: 130.25
Site Type: Channel Disturbance, Riparian Corridor Removal.
Bank Height: 9 feet
Bank Length: 228 feet
Technique: Back-sloping and riparian corridor reforestation.

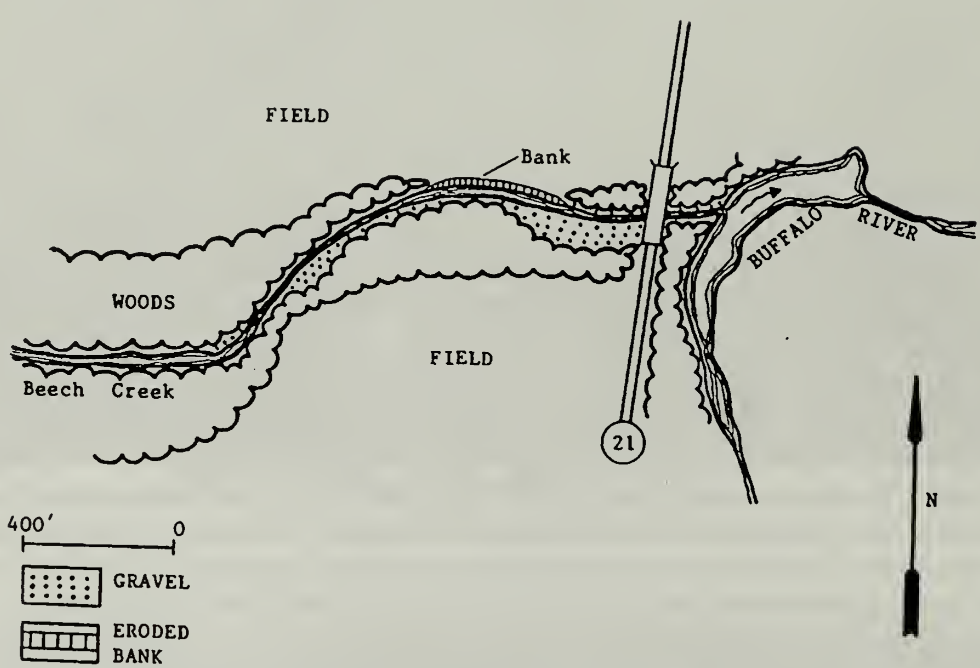


Figure 11: Planform sketch of the Beech Creek Site.

Pre-Project Site Description

This site is located just above the confluence of Beech Creek and the Buffalo River. This section of Beech Creek channel was reamed out with a bulldozer as recently as 1989. Much of the material pushed out of the channel was dozed up onto the bank to "armor it" against floodwaters. While the naked part of the bank was somewhat stabilized by this process, the downstream forested buffer was being destroyed. There was a well-vegetated floodplain opposite the treated bank at a lower elevation. The bank grades from sand at the top through, gravel, cobble and small boulders near the base. Bedrock is visible in the channel and a point bar is forming on the opposite side of the channel. A highway bridge about 600 feet below the lower end of reach should limit the amount of lateral migration this site can experience. The eroding bank, which is approximately 9 feet high and 228 feet long, is being propagated into the downstream buffer area by scour below the root zone. This leads to trees toppling off the top of the undercut bank. The channel straightening and reduction in roughness brought on by the bank armoring work worsen the scour. Both straightening and reduction in roughness lead to higher velocity floodwaters impinging on the downstream portion of the bank. The toe of the treated site is now stable, but reduction in hydraulic roughness from bank armoring has caused the riparian buffer to be eroded further downstream of the site. Based on measurements taken from 1972 and 1992 aerial photos, the eroding bank has grown about 100 feet in length over the 20-year period as the downstream end of the buffer continues to erode.


Photo 5: View downstream of Beech Creek Site (1994).


Photo 6: View down stream of Beech Creek Site (2001).

Project Description

A cedar revetment did not need to be constructed at this location because the toe of the bank has already been stabilized with large boulders, and mimosa trees were also growing on the lower portion of the bank. The mitigation action taken included back sloping 228 feet of the vertical component (upper 5 feet) of this bank to a 45-degree slope, transplanting of river cane rhizomes and planting seedlings on a 4 X 4 grid within the back-sloped portion of the bank. The 100-foot buffer area was then planted with seedlings on an 8 X 8 grid.

Summary of Project results

Overall Summary – Efforts here have been 100% successful. This bank has stabilized and is beginning to revegetate. There is no active erosion at this site or in the downstream buffer. There are 1 to 2 inch sycamore, sweet gum, walnut trees and sumac bushes populating the bank and a variety of dense annual vegetation. There are willows at the toe of the bank on the upstream end moving the water away from the toe of the bank. The bank is no longer eroding and is holding a one to one slope. There is heavy elk use here and that could be a concern in the future.

Photo 7: View from upstream of Beech Creek Site (2001).

Ferguson

River Mile: 127.5
Site Type: Channel Disturbance, Riparian Corridor Removal, Disturbance Zone
Bank Height: 9 feet
Bank Length: 450 feet
Technique: Cedar tree revetment and riparian corridor reforestation, whole willow transplanting

Photo 8: 1992 aerial photo of Ferguson Site area.

Pre-Project Site Description

This site is located on the main channel of the Buffalo River inside the Boxley Valley National Historic District. This section of the main channel of the Buffalo River was reamed out with a bulldozer as recently as 1989. Much of the material was dozed up onto the bank to "armor it" against floodwaters. While this did protect the bank for a short time, the downstream end of the bank became exposed and a vertical face was beginning to erode. There is a well vegetated point bar forming between the main channel across from the bank and an overflow channel on river right. The bank grades from a sandy clay loam through gravel, cobble and small boulders near the base. The bank is 9 feet high and more than 450 feet long and was being propagated into the downstream buffer area by scour below the root zone.


Photo 9: Downstream view of Ferguson bank (1993).


Photo 10: Downstream view of Ferguson bank (2001)

Project Description

The downstream portion of the bank was back sloped to a 1:1 slope and a two row cedar tree revetment was installed along the entire length of the bank in 1995. The upstream portion of the bank was not back-sloped due to other resource considerations. Native river cane was planted along the face of the back-sloped bank and an attempt was made to transplant hardwood saplings along the top of the slope. Native hardwood seedlings were planted inside the riparian buffer on an 8X8 foot spacing. Due to an extreme flood event, repairs on the revetment were made in 1996. Cedar trees were replaced on the entire revetment in 2001 using most of the existing anchors.

Summary of Project Results

Overall Summary – The bank is stable and supporting vegetation. The thalweg is running along the revetment on the upstream 2/3 of the bank. The downstream 1/3 of the bank has good growth of willows and juvenile sycamores along the toe and between the stream and the bank. The bank slope is supporting moderate annual vegetation and a variety of native tree growth. As can be seen in the cross section survey of this site (Appendix A) the main channel is moving from the channel in front of the bank into the overflow channel on river right across from the bank. Although the revetment had to be rebuilt due to age, stream velocity in this headwaters reach, and other factors have not allowed a great deal of natural vegetation to populate the bank and it is our opinion that given time this bank will stabilize. Private property is located just beyond the bank causing us to put extra effort into stabilizing this eroding cutbank.

Photo 11: Upstream view of Fergusion revetment (2001).

Cecil Creek

River Mile: 109.3
Site Type: Confluence, Riparian Corridor Removal
Bank Height: 8 to 10 feet
Bank Length: 210 feet
Technique: Cedar tree revetment and riparian corridor reforestation

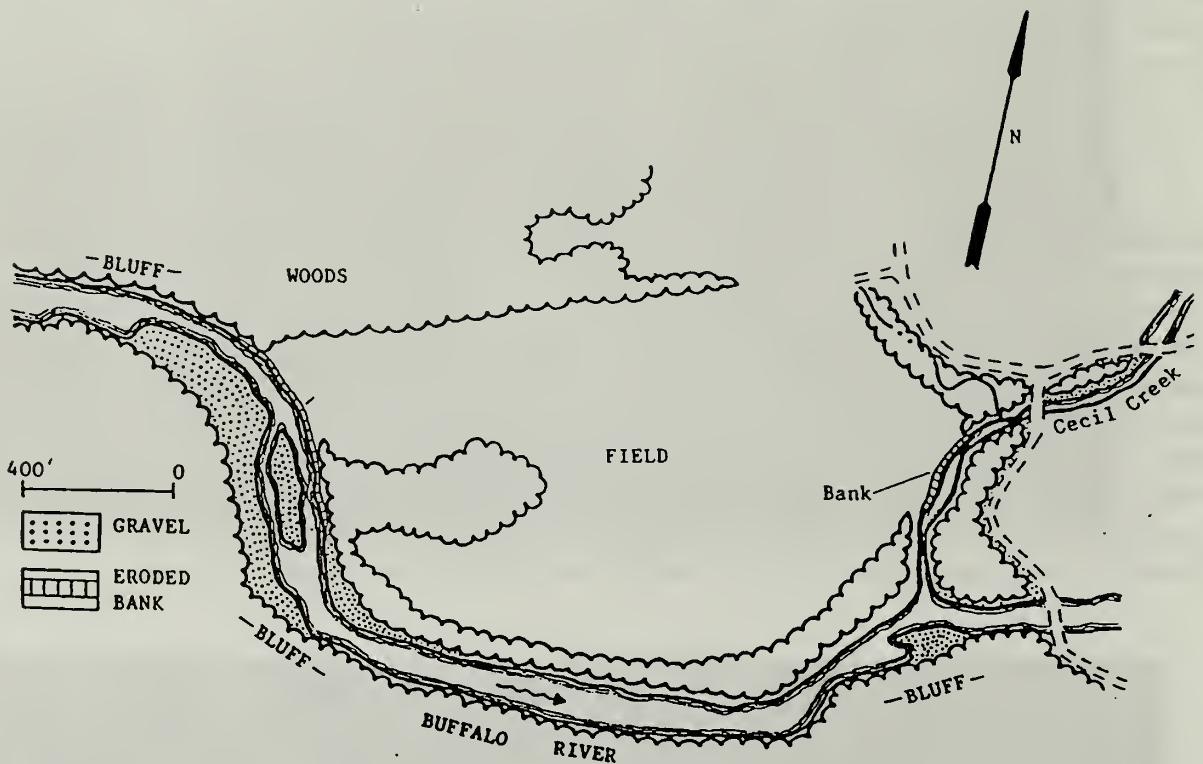


Figure 12: Planform sketch of the Cecil Creek Site.

Pre-Project Site Description

This site is located on Cecil Creek just above its confluence with the Buffalo River. The cutbank at this site is nearly vertical. The opposite side is a well-vegetated channel shelf. The bed is generally cobble that is being brought down from the very steep drainage of upper Cecil Creek. The bank material is mainly clayey silt in the higher portions of the bank and cobble dominates the lower bank. This site is vertically controlled by cobble. The Buffalo River channel provides downstream control. Erosion at this site is due to natural confluence instability and removal of the riparian corridor. The dominant mechanical process appears to be block failure driven by slaking and scour. The eroding bank is between 8 and 10 feet high and 210 feet long. Average lateral migration rate from 1972 to 1992 was approximately 1 foot/year based on the examination of aerial photographs. There was a significant and healthy looking riparian and stream side forested buffer along this reach observed on the 1972 aerial photographs. Because this is a naturally unstable confluence site, this represents an area that would naturally be effected by channel shifts. Unfortunately, the erosion has transgressed into an area where agricultural use has removed all the trees and the erosion can move very rapidly under these conditions.

Photo 12: View upstream of Cecil Creek Confluence Site (1994).

Photo 13: View upstream of Cecil Creek Confluence Site (2001).

Project Description

A double row cedar tree revetment was installed at this site in 1996 (approximately 16 trees). Due to other resource considerations the decision was made not to back-slope this site. Instead the upper portion of the bank, which contained a heavy growth of river cane, was pulled down on top of the revetment after the trees were anchored to the bank using #88 duck bill anchors and 3/16 inch cable. In 1994, 1995, and 1996 native hardwood seedlings were planted in a 100-foot wide riparian corridor on an 8X8-foot grid in the areas where river cane was not growing.

Summary of project results

Overall Summary - This site is stable and no longer eroding. The cedar tree revetment is completely intact and the bank above the revetment is covered with river cane. There is dense river cane growth on top of the bank. The upper row of cedar trees are covered with deposition and the bottom row is 50% covered. There is river cane growing out of the upper row. The thalweg is along the bottom row of cedar trees. The stream channel is deeper and narrower and the point bar across from the bank is becoming populated with sycamore trees.

The upper, middle, and lower third portions of the bank are essentially the same. The upper row of cedars is covered with deposition and has river cane growing above it. The bottom row is half covered with deposition and half of it is below the average water level.

Photo 14: View of Cecil Creek Confluence Site from across stream, after river cane was pulled down on top of the revetment (1995).

Angle Field

River Mile: 105.2
Site Type: Valley Crossover
Bank Height: 20 feet
Bank Length: 200 feet
Techniques: Cedar tree revetment, streambank back-sloping and revgetation, riparian corridor reforestation.

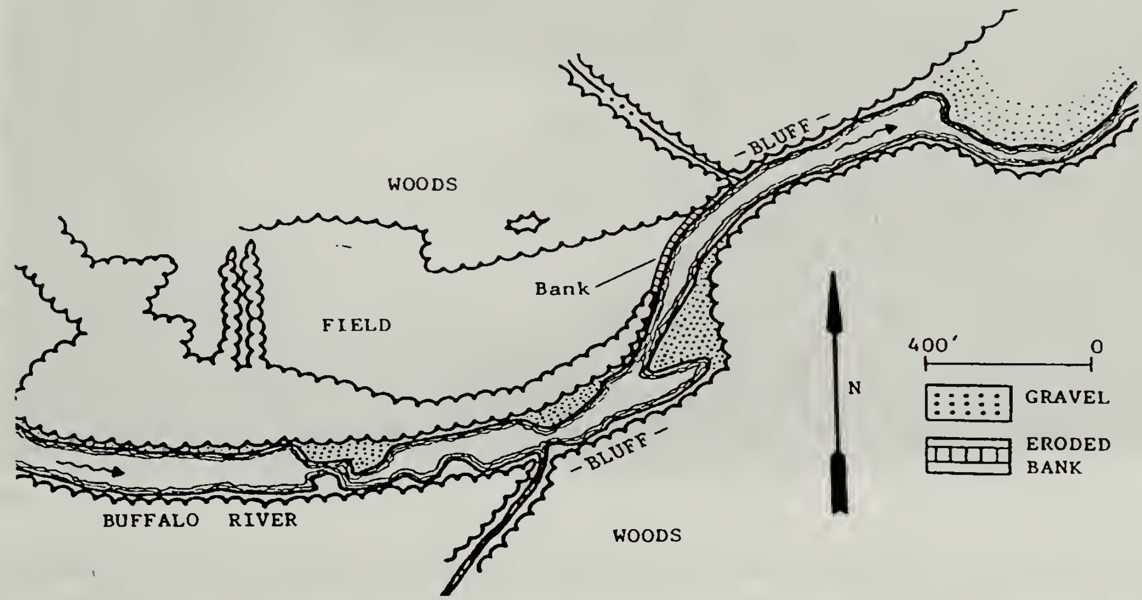


Figure 13: Planform sketch of the Angle Field Site.

Pre-Project Site Description

This site is located on the main channel of the Buffalo River. It is a valley crossover reach where the upstream and downstream controls are provided by the bedrock bluffs above and below the crossover reach. The left bank was completely covered by slump scarps along the area that is eroding and is adjacent to an agricultural field. The portion of the eroding bank with remaining riparian buffer (lower end) appears to be suffering mainly from scour below the root zone. The opposite bank has a lower flood plain, but the trees are fairly large indicating that the far side is not aggrading rapidly. The upstream end is beginning to form a more stable geometry. The bed material is dominantly gravel with a lesser component of cobble. Bank height is 20 feet and length to be reveted is 200 feet. The eroding bank extends for another 200 feet below the portion to be back sloped, but has a healthy riparian buffer already established on the top of the bank and large boulders along the toe (Photo 15). Bank material consists of mostly sand with a few feet of gravel and cobbles at the toe. Slump scarps dominate most of the erosion area. There is also evidence of rill erosion on the upper portion of the bank and scour along the lower section. This bank has moved very little in the past 20 years based on aerial photo interpretations. The bank appears devoid of vegetation and the channel configuration is relatively similar on each photo. The rate of erosion is probably less than one foot per year. The riparian corridor has slumped off throughout most of the length of this bank. The buffer below the agricultural field is being impacted by the slumping next to the field because this instability is being propagated downstream.

Photo 15: View downstream of the lower portion of the Angle Field Site (1994).

Photo 16: View downstream of the lower portion of the Angle Field Site (2000).

Project Description

A pre-project geomorphic cross section and planview survey of the project site was conducted. Five permanent survey monuments were installed in the field and wooded area adjacent to the site and cross-sections of the site were taken from each monument. The bank was back-sloped to approximately a 1:1 slope and native river cane rhizomes were planted in the bank. A two-row cedar tree revetment was installed (approximately 42 trees) along and above the toe covering 10 to12 feet of the 20 foot back-sloped bank. The cedar trees were anchored using #88 duck bill anchors and 3/16 inch cable. Native seedlings were planted using 8x8-foot spacing inside a 100-foot wide riparian buffer and along the top portion of the back-sloped bank. The revetment and rhizome planting portion of this project was completed in 1995, the seedlings were planted in 1994, 1995, and1996.

Summary of Project Results

Overall Summary – The restoration rate at this site is less than desirable, but the general trend is toward stability. The revetment is holding well, but showing some age. There is relatively good vegetation growth along the top of the bank, but the majority of the bank is devoid of vegetation. Heavy elk use in this area combined with very sandy soil content is apparently slowing the revegetation process. Three of the five cross section surveys (Appendix A) show the channel to be somewhat deeper than in 1994. However, overall very little change has occurred in the channel.

Upper Third – The top row of the revetment is 100% covered with deposition and the bottom row is about 65% covered. There is sparse vegetation with a few 1 to 11/2 inch trees on this bank portion. Elk and deer appear to have been especially hard on this section.

Middle Third – This bank section is much like the upper section except more of the bottom row of trees is exposed and appears to be giving-way.

Lower Third – The bottom row in this section is completely exposed. The top row is 90-100% covered with deposition. There is some river cane and annual vegetation growing on the second row.

Rock Creek (lower)

River Mile: 93.45
Site Type: Confluence
Bank Height: 14 feet
Bank Length: 250 feet
Technique: Cedar tree revetment, streambank back-sloping and revegetation, riparian corridor reforestation.

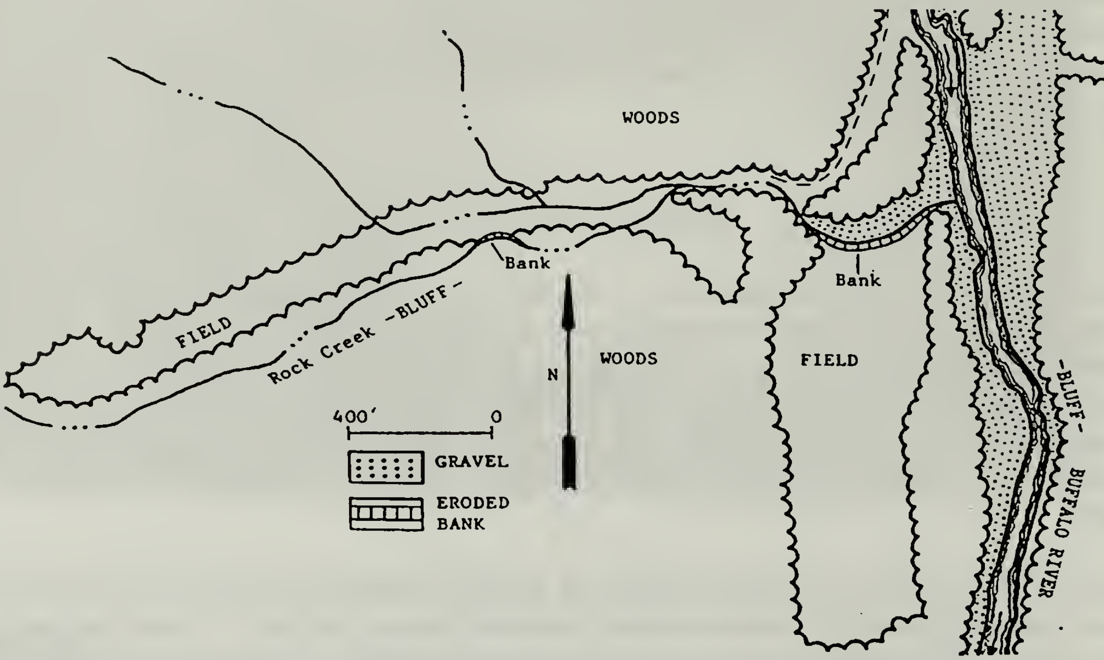


Figure 14: Plan form sketch of the Rock Creek (upper and lower) Sites.

Pre-Project Site Description

The site is located immediately above the confluence of Rock Creek with the Buffalo River (Figure 5). The bank top has been cleared for agricultural use. The eroding bank at the project site is 14 feet tall and 250 feet long. The channel shape is very uniform with a tall cut bank on the right side and a very low point bar on the other. The site is affected by backwatering and other processes associated with confluence sites. The bed material is dominantly gravel with very little cobble and a few isolated clumps of resistant clay. The bank is composed of silty sand with some clay layers. The lower portion is dominated by gravel with several gravel layers occurring nearly half way up the bank. These gravel layers are often covered by slump sand. The riparian corridor is thin throughout the length of this stream as it runs along the agricultural use area. At the eroding bank the thin wooded buffer has been breached leaving only unconsolidated sediments to counter erosional forces. Upstream/downstream control is chaotic and variable and is very dependent on backwatering process as driven by the Buffalo River. The dominant erosion processes are scour at the toe and slumping, which are driven by the lack of vegetation on the bank and flood plain, the steep angle of the bank and the variable strata. The erosion rate is estimated to be approximately 3.5 feet per year as determined from the 1972 and 1992 aerial photographs. Ground monitoring from 1985 through 1991 indicated an erosion rate of nearly 7 feet per year.


Photo 17: View downstream of Lower Rock Creek Site (1994).

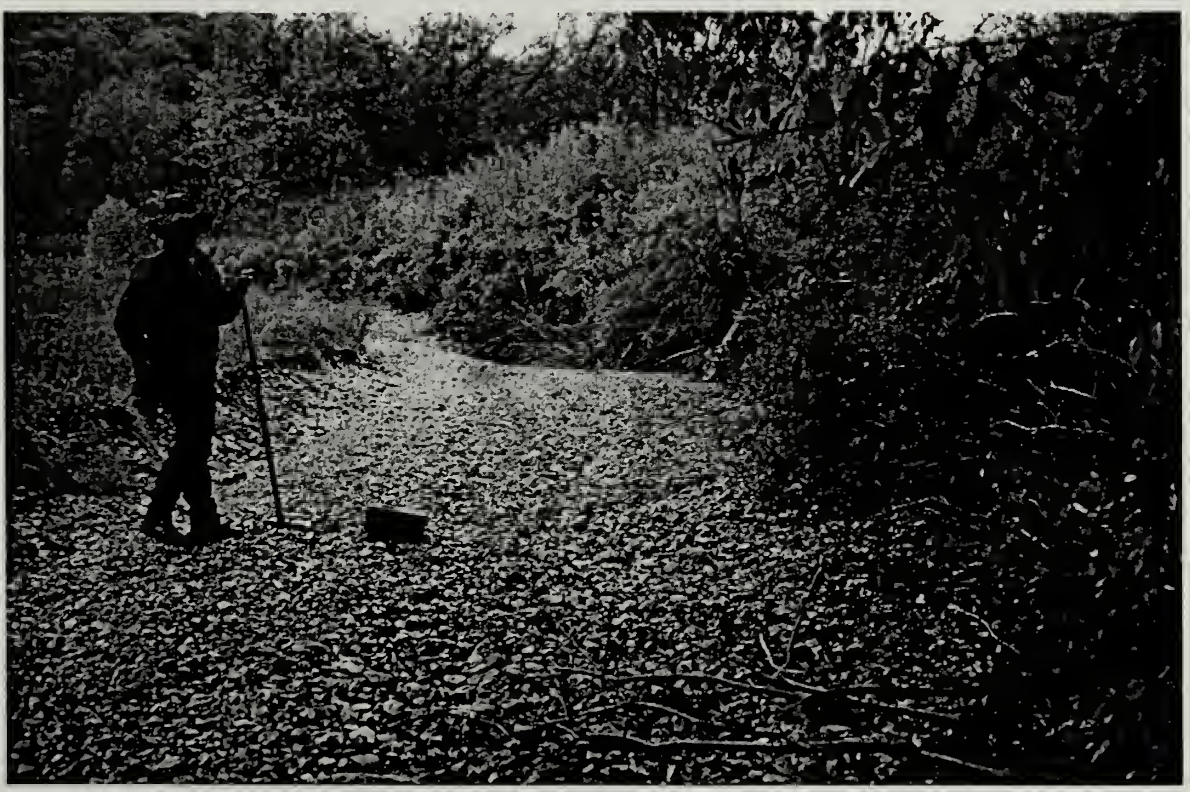


Photo 18: View downstream of lower Rock Creek Site (2000).

Project description

A pre-project geomorphic cross section and planview survey of the project site was conducted. Four permanent survey monuments were installed in the field adjacent to the site and cross sections of the site were taken from each monument. The bank was back-sloped to approximately a 1:1 slope and native river cane rhizomes were planted in the bank. A two row cedar tree revetment was installed (approximately 42 trees) along and above the toe covering 10 to12 feet of the 20 feet back-sloped bank. The cedar trees were anchored using #88 duck bill anchors and 3/16 inch cable. Native seedlings were planted using 8x8-foot spacing inside a 100-foot wide riparian buffer and along the top portion of the back-sloped-bank. The revetment and rhizome planting portion of this project was completed in 1994 the seedlings were planted in 1994, 1995, and1996. In 1996 maintenance was necessary due to elk damage – four cedar trees were replaced on the up stream end of the revetment.

Summary of Project Results

Overall Summary - This project has successfully slowed bank erosion and the bank and riparian corridor have begun to revegetate. All of the stream channel cross sections (Appendix A) show the channel to be narrower and deeper than when originally surveyed in 1994, indicating a return to a more natural stream channel. The bank slope overall is holding at 1:1, and revegetation of the riparian corridor is slowly occurring. Heavy elk grazing and trampling appears to be greatly hampering revegetation on both the bank and riparian buffer. The upstream end of the revetment could use some minor repair work.

Upper Third – The bank here appears to be stable. However 20 to 30 feet of the upper portion of the revetment is gone. Some slumping is evident and about 20 feet of vertical bank face is exposed and eroding. There is a heavily used elk trail cutting through this portion of the bank. The bank upstream and downstream of the exposed area is stable with a good covering of ground vegetation, willows and river cane. The stream channel in this section has narrowed and cut deeper as can be seen in the Cross Sections A and AB1 (Appendix A).

Middle Third – This section is in excellent condition. There are dense river cane and numerous 1 to two-inch trees growing along the top of the revetment. The revetment is 80 to 90% covered with deposition. The stream channel in this section has cut deeper and is beginning to narrow as can be seen in cross section AB2 (Appendix A).

Lower Third – This section is stable with deposition filling both rows of the revetment. There is one erosion trench one-foot or so deep that has been created as a result of frequent elk use. This section has also begun to narrow and deepen as can be seen in Cross Section B (Appendix A).

Rock Creek (upper)

River Mile: 93.5
Site Type: Confluence, riparian loss
Bank Hight: 6 feet
Bank Length: 155 feet
Technique: Cedar tree revetment, streambank back-sloping and revegetation, riparian corridor reforestation.

Pre-Project Site Description

The site is located on Rock Creek approximately 1,500 feet above the confluence with the Buffalo River. The bank top has been cleared for agricultural use. The eroding bank at the project site is about 6 feet tall and 155 feet long. The channel consists of rough and undulating cut bank on the erosion side and slipoff slope and fresh gravel on the opposite aggrading side. The bed material is dominantly gravel, intermixed with cobble in places. The bank is clay/silt with some sand. The lower portion is dominated by gravel with some rocks interspersed throughout the bank. There are also some resistant clay outcrops near the bottom which stick out into the stream along the eroding bank. The riparian corridor is thin throughout the length of the stream as it runs along the agricultural use field. At the eroding bank the thin wooded buffer has been breached leaving only unconsolidated sediments to counter the erosional forces. The creek is against a bluff line on the far side both above and below the site providing upstream/downstream control. The dominant erosion processes are scour and slaking along the bank, which set up conditions for subsequent block failure. The erosion rate is estimated to be approximately one foot per year as determined from the 1972 and 1992 aerial photographs.

Photo 19: Large tree root-wad, uprooted from hillside opposite revetment. Person on right is pointing toward root-wad (1997).

Photo 20: View downstream of Upper Rock Creek Site (1994).

Photo 21: View downstream of Upper Rock Creek Site (2000).

Project Description

The bank was back-sloped to a 1:1 slope leaving a bank approximately 9 feet from toe to top. A single row cedar tree revetment was installed (approximately 15 trees) along the toe and up the bank covering the toe and 5 to 6 feet of the face of the bank. The cedar trees were anchored using # 88 duck bill anchors and 3/16 inch cable. Native river cane rhizomes were planted along the back-sloped bank. Native seedlings were planted using 8X8-foot spacing inside a 100-foot wide riparian buffer. The revetment and rhizome planting portion of this project was completed in 1995. Native seedlings were planted in 1994, 1995 and 1996. No maintenance has been needed at this site.

Summary of Project Results

Overall Summary – This project has successfully slowed erosion at the site however some erosion is still occurring on the lower portion of the bank. The bank is stable and the upstream two-thirds supports dense river cane growth above the revetment. The downstream one-third has an exposed vertical face with very little vegetation. The thalweg is along the bottom of the cedar tree revetment on the down stream portion and has eroded out behind a twenty foot section of the revetment forming a small pool. The riparian corridor and the majority of the bank have began to revegetate and there is good deposition in most of the revetment holding the bank slope to 1:1. Part of the reason for the loss of the lower end of this revetment is the result of an unusual circumstance. In 1997 a huge (4' DBH) sweet gum tree was uprooted from the hillside opposite the revetment and slid down into the creek (Photo 19). The root wad was so large as to nearly block the entire channel. Because this was a natural event we did not attempt to remove the log or root wad and waited to see if the tree would be floated out or the creek cut around the obstruction. As it turns out both things happened and a portion of the revetment was lost in the process. However, it appears that this bank is well on its way to returning to its natural trend of inherent stability, which is the goal.

Upper Third – The bank is stable with good deposition along the toe and in both rows of the revetment. There is dense river cane growth in the upper portion of the first row.

Middle Third – There is less deposition at the toe, but otherwise it is the same as the upper third.

Lower Third – The upper portion of the lower third is stable, but the lower two-thirds has given-way. The bank has been back cut behind the revetment and some slumping has occurred.

Sheldon Branch

River Mile: 92.5
Site Type: Overbank Scour, valley cross-over
Bank Height: 12 feet
Bank Length: 420 feet
Technique: Cedar tree revetment, streambank back-sloping and revegetation, riparian corridor reforestation.

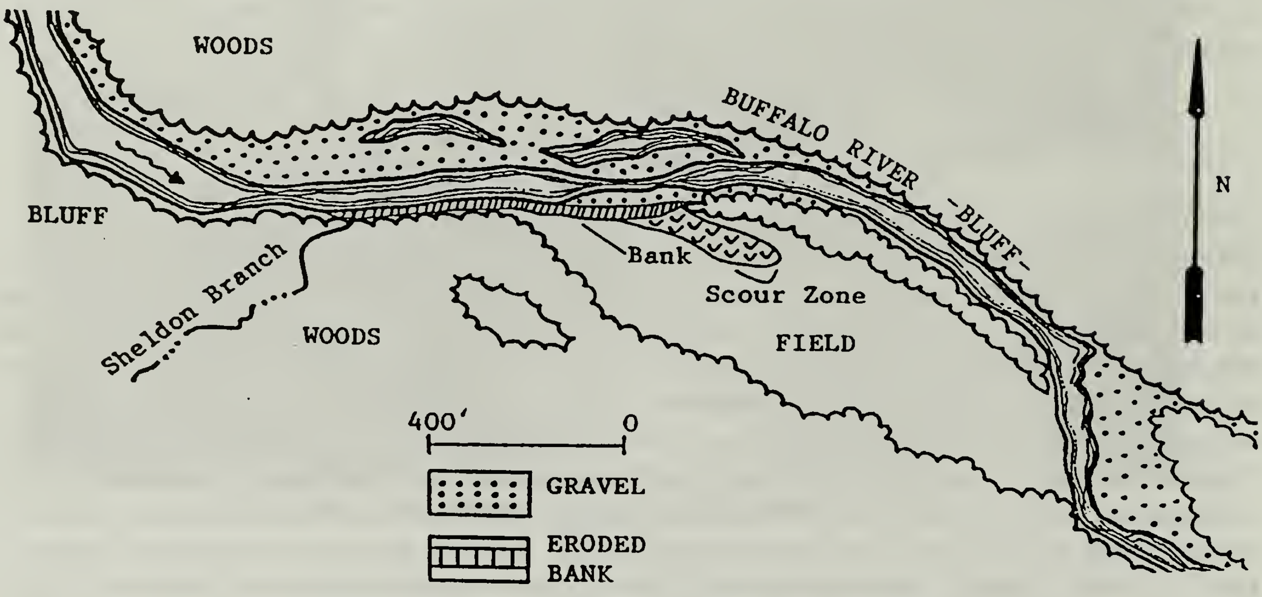


Figure 15: Planform sketch of the Sheldon Branch Site.

Pre-Project Site Description

This bank is located on the main channel of the Buffalo River just down-stream from the mouth of Sheldon Branch (see map in Appendix B). The eroding bank is at the upstream end of the main channel overbank flow line, where flow from the channel enters the floodplain. Flow exiting the river channel is eroding the bank, which is weakened by a lack of riparian trees. The absence of hydraulic roughness allows high over bank flow velocities, which also contribute to the instability. The channel appears to become narrower at the lower end as it approaches the bedrock bluff near the downstream terminus of the eroding bank. This combined with the retreat of the bank and widening of the channel results in the aggradation of sediment in the channel and the formation of a mid-channel island. The bars form as the bank erodes, and bars become more resistant to erosion because they revegetate with dense willows. The eroding bank is very rough, with scalloping and shelving controlled by differential resistance of the various alluvial layers. The bank height is approximately 12 feet and it is 420 feet in length. Bank slope ranges from gentle to nearly vertical. The bed is composed of gravel with interspersed cobbles. The bank is composed of a mix of stratified sandy silt with some clay. A cobble layer is visible near the toe. Some strata are almost pure sand. There is bedrock lateral control immediately upstream and downstream of the reach. Vertical control is not immediately apparent. Bank retreat from 1972-1992 aerials is 5-10 feet/year. No ground monitoring has been performed at this site. A thin riparian buffer can be observed on the 1972 aerials. These trees were probably lost to slumping as described above.

Photo 22: View upstream of the Sheldon Branch Site (1994).

Photo 23: View upstream of the Sheldon Branch Site (2001).

Project Description

Pre-project geomorphic cross section and planview survey of the site was conducted. Four permanent survey monuments were installed in the field adjacent to the site and cross sections of the site were taken from each monument. The bank was back-sloped to approximately a 1:1 slope and native river cane rhizomes were planted in the bank. A two row cedar tree revetment was installed (approximately 65 trees) along and above the toe covering 10 to12 feet of the 20 foot back-sloped bank. The cedar trees were anchored using #88 duck bill anchors and 3/16 inch cable. Native seedlings were planted using 8x8-foot spacing inside a 100-foot wide riparian buffer and along the top portion of the back-sloped bank. The revetment and rhizome planting portion of this project was completed in 1994 the seedlings were planted in 1994, 1995, and1996.

Summary of Project Results

Overall Summary – Restoration and stabilization efforts at this site have been one hundred percent successful. The bank above the revetment, the revetment area, and the area between the revetment and stream are completely covered with native trees, river cane, and dense annual vegetation. Both rows of the cedar tree revetment are completely covered with deposition. The native seedling and rhizome planting efforts have been successful. Mature river cane and two to three inch trees are growing on the entire bank. The bank has held at a one to one slope. The stream channel has moved out well away from the bank and a lateral bar is beginning to form and revegetate between the stream and project area. The only problem at this site has been with the replanting of the riparian corridor. Heavy elk use in this area of the river has resulted in a higher than normal seedling mortality rate.

Photo 24: Close-up view of vegetation at Sheldon Branch Site (2001).

Jamison Creek

River Mile: 72.5
Site Type: Disturbance Zone
Bank Height: 12 feet
Bank Length: 2340 feet
Technique: Cedar tree revetment, streambank back-sloping and riparian corridor reforestation.

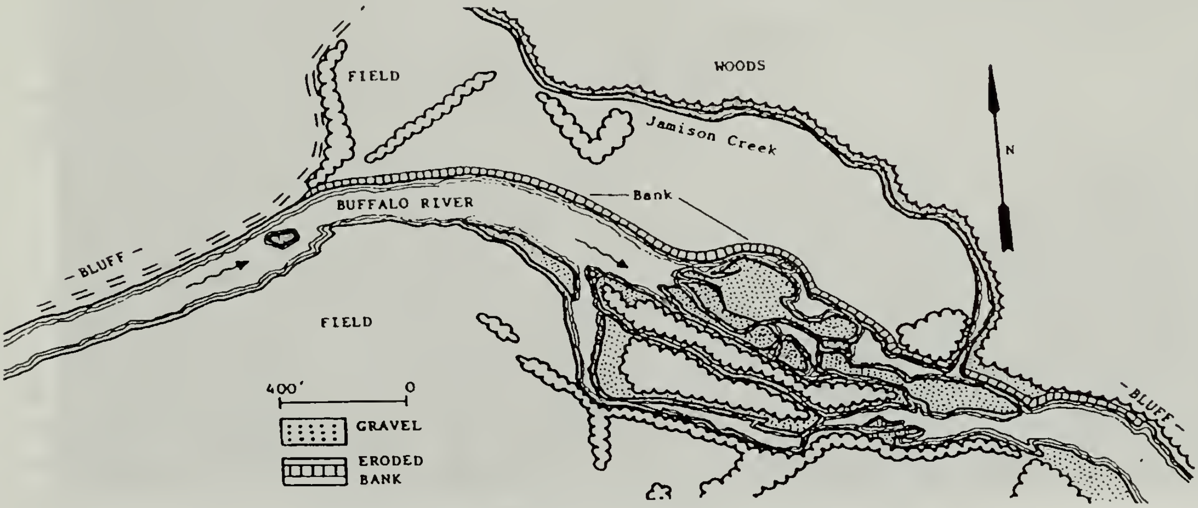


Figure 16: Planform sketch of the Jamison Creek Site.

Pre-Project Site Description

This site is located on the main channel of the Buffalo River just above Jamison Creek. The eroding bank is 12 feet high and 2340 feet in length. Upstream of this site the river has eroded up against the Woolum road and the adjacent bluff. BUFFs maintenance division has constructed a massive hard structure about 100 yards above the eroding bank to prevent slumping and erosion of the road. Slumping, scour, block failure, and over bank flow scour are all active processes along this bank. The middle and lower portion of the bank has an undulating or corrugated morphology which encourages eddy currents and scour. Downstream at the lower end of the bank the river is controlled vertically by a shelf of bedrock, which helps force the lateral erosion process into this naked bank. The channel is very unstable, over widened, and forming a braided pattern toward the lower one-half of its length. Approximately ten different islands and a dozen flow routes have formed in the lower channel. Bed material is dominantly gravel size chert with some cobbles. The bars and islands in the lower portion of the channel have thick growths of willows attempting to stabilize them. The bank material is composed of silty sand with some clayey lenses and gravel in the lower 4 or 5 feet. Erosion rates have been documented as high as 24 feet per year along the middle and lower stretches of the bank from field measurements taken between 1985 and 1991. Average erosion rates as estimated from this work and aerial photographs are 14 feet per year over a 20-year period for the middle and lower section and between 2 and 4 feet per year for the upper 700 feet. The riparian corridor has been completely destroyed by past agricultural activities on both banks. Fields of fescue and milkweed are the only vegetation left on the tops of the banks. Cattle still have access to the river and the riparian corridor on the far bank and can wander across the river and up the eroding bank. The lower terminus of this bank is cutting in and under a healthy riparian forest.

Photo 25: Upstream of upper portion of the Jamison Creek Site (1994).

Photo 26: Upstream of upper portion of the Jamison Creek Site (2001).

Project Description

The bank was back-sloped to approximately a 45° slope. A two row cedar tree revetment was installed (approximately 115 trees) along and above the toe covering 10 to12 feet of the 20 foot back-sloped bank. Due to the severe erosion and tight radius of curvature associated with the lower 1500 feet of this bank, only the upper 850 feet were stabilized with the cedar revetment. The cedar trees were anchored using #88 duck bill anchors and 3/16 inch cable. Due to the amount of cobble at this site a pneumatic hammer was sometimes needed to pre-drill the holes used for the #88 duck bill anchors. Native seedlings were planted using 8x8-foot spacing inside a 100-foot wide riparian buffer and along the top portion of the back-sloped bank. The revetment portion of this project was completed in 1996, and the seedlings were planted in 1994, 1995, and1996.

Summary of Project Results

Overall Summary – Stabilization and restoration techniques used at this site have been successful. Native hardwoods, sycamore trees, willows and annual vegetation are growing on the bank slope within and above the cedar tree revetment. The water is significantly deeper in front of the revetment. The double row revetment is below the water level the majority of the time and the cedar trees are partially filled with deposition. There is an exposed vertical bank at the downstream end of the revetment where a small portion of the bank has eroded away behind the revetment. The revetment appears to be well anchored and holding the stream away from the bank.

The upper, middle, and lower thirds of the bank are as described above.

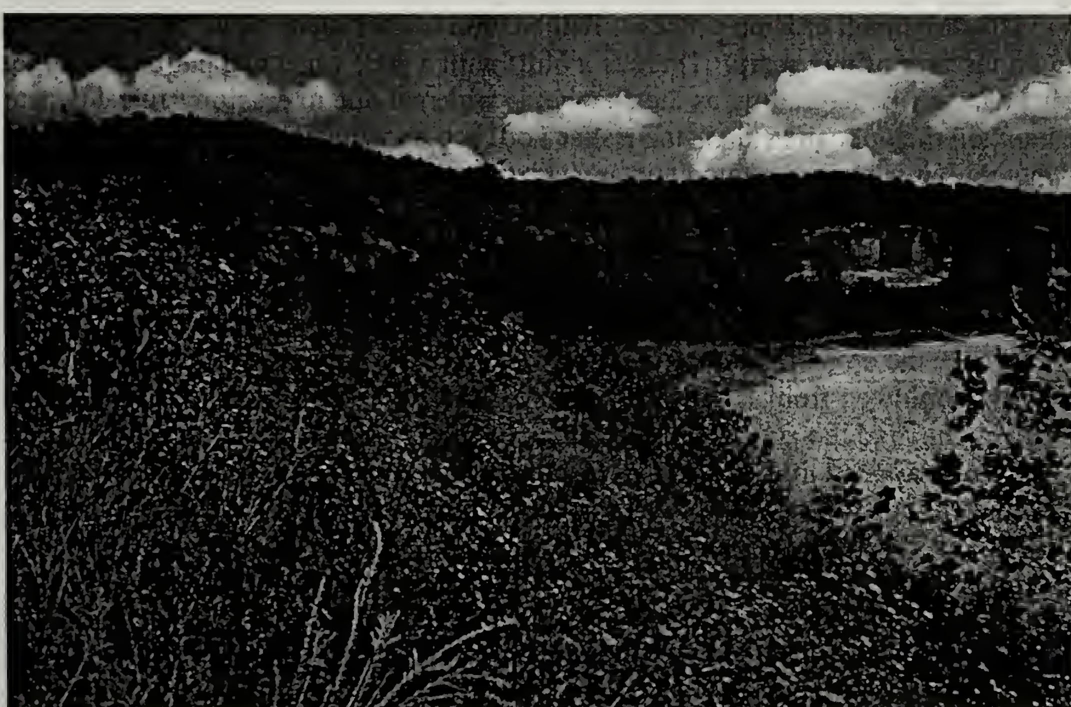


Photo 27: View looking downstream at Jamison Creek Site (2001)

Baker Ford

River Mile: 63.5
Site Type: Massive Slump Zone
Bank Height: 24 feet
Bank Length: 1,000 feet
Technique: Cedar tree revetment and establish and fence a buffer zone.

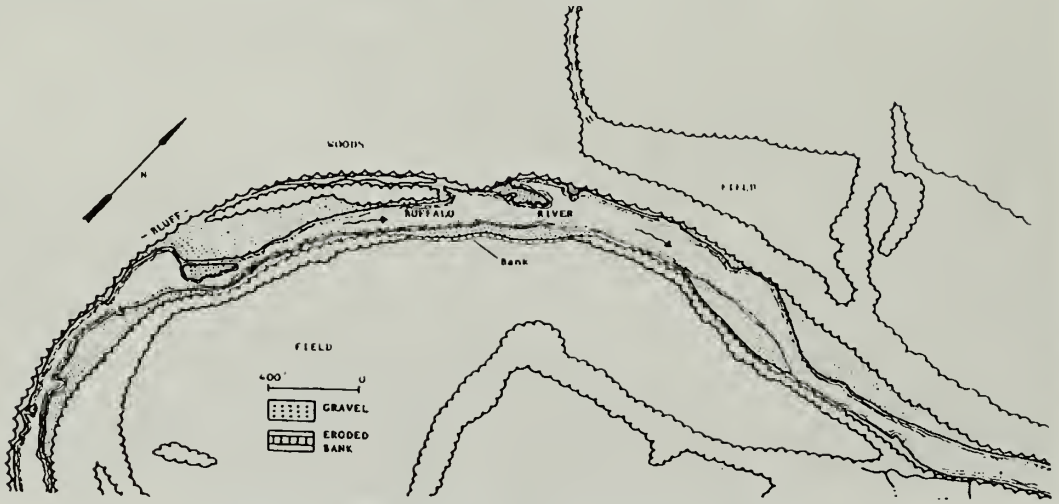


Figure 17: Planform sketch of the Baker Ford Site.

Pre-Project Site Description

This site is located on the main channel of the Buffalo River across the river from the Baker Ford public access and canoe launch area. Bank height averages 24 feet from toe to flood plain level. The length of the bank is 1,000 feet with the lower 500 feet in what appears to be the active zone. Slumping is the dominant erosion process. Rill erosion is also apparent as flood plain drainage rushes down the face of this scarp. There is a bluff with a well vegetated bar on the opposite shore. This bar may be aggrading as the channel is widened due to erosion. Just downstream from the bank on the opposite side is the Baker Ford access which has a very gentle slope and low bank height but is well vegetated and appears to be very stable in spite of the fact that it is on the cut bank side of the river. About half way up the lower bank is a zone of cemented sand that appears to be acting as an aquiclude, keeping moisture in the upper portion of the bank and probably encouraging the slumping process. The bed is dominantly gravel with cobbles interspersed. The bank is dominantly composed of homogenous sand. As determined from the aerial photographs the erosion rate is 5 feet per year. Ground based erosion monitoring indicates erosion rates have slowed from 1985 - 1991, but this is a result of the erosion being propagated downstream and beyond the zone originally included in the monitored reach. The riparian corridor that was visible in this area on the 1972 aerial photographs (stream-side trees) has been removed by the slumping process which extended behind the streambank and into the flood plain. Stream side vegetation is present both above and below the eroding bank and is trying to recolonize the upper portion of the slump bank. The downstream vegetation is being heavily impacted by the ongoing erosion and slumping and scour around the base of the remaining trees is propagating the erosion in the downstream direction. Continued access by cattle is interfering with the ability of vegetation to re-colonize those sections of the bank which are trying to stabilize on their own.

Photo 28: View downstream of Baker Ford Site (1994).

Photo 29: View downstream of Baker Ford Ssite (2000).

Project Description

A two row cedar tree revetment was installed (approximately 160 trees) along and above the toe covering 10 to15 feet of the eroding bank. The cedar trees were anchored using #88 duck bill anchors and 3/16 inch cable. A barbed wire fence (2200 ft.) was constructed to establish a 100-foot wide buffer zone back from the bank.

Summary of Project Results

Overall Summary – Stabilization efforts here have been very successful. The entire revetment is still intact. The upper row of cedar trees are completely covered with deposition and the second row is more than fifty percent filled with deposition. The revetment has 1 to 11/2 inch juvenile sycamore trees and annual vegetation growing out of it. The bank is beginning to rebuild below the revetment and supports willows, sycamores and other vegetation between the revetment and the waters edge.

Upper Third – This portion of the bank is very stable and is revegetating nicely. The upper row of cedar trees are completely covered with deposition and the second row is fifty to seventy five percent covered. One inch sweet gum and sycamore trees are growing throughout and below the revetment. There are willows and annual vegetation growing profusely out of the revetment and below it to the waters edge.

Middle Third – The middle third is almost identical to the upper third. The only exception being that the second row of cedar trees is slightly more exposed.

Lower Third – This portion is the most stable. There are trees and annual vegetation on the bank above the revetment as well as in and below it.

Photo 30: View from across stream of Baker Ford Site (2001).

Calf Creek

River Mile: 60.3
Site Type: Confluence
Bank Height: 12 feet
Bank Length: 400 feet
Technique: Cedar tree revetment, streambank back-sloping and revegetation, riparian corridor reforestation.

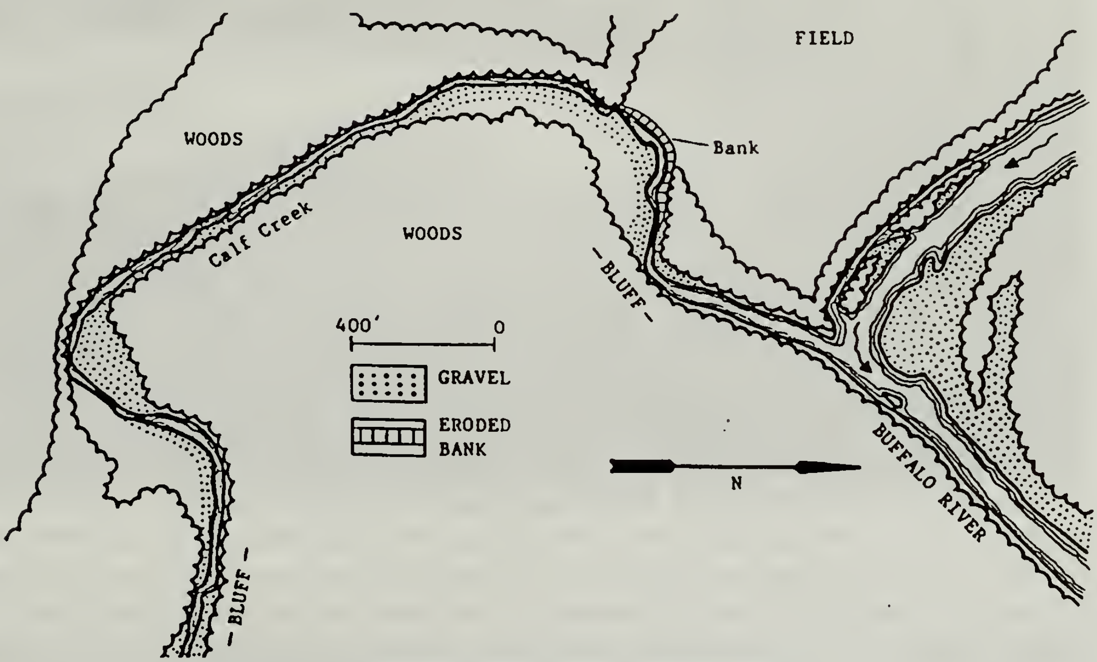


Figure 18: Planform sketch of the Calf Creek Site.

Pre-Project Site Description

This site is located on Calf Creek approximately 600 feet above its confluence with the Buffalo River. The length of the bank without any buffer is 400 feet while another 100 feet of bank extends as an undercut below the downstream buffer. The bank averages about 12 feet high. The channel has a classic point bar to cut bank profile. Undercutting and scour at the toe combined with slaking and block failure are the dominant erosional processes acting on this rapidly eroding bank. The bed is composed of gravel, as is the slip off slope on the other side of the eroding bank. The bank is migrating so rapidly that very little recruitment of vegetation has occurred on the point bar. The cut bank is composed of very well consolidated sandy silt with gravel and cobbles at the toe. There is a layer of bedrock visible in the rapids at the downstream end of the eroding bank. The creek appears to be trying to cut around this layer of vertical control similar to what the river is doing at the Jamison Creek disturbance zone. The right bank has lateral bedrock control just downstream from the site. No upstream vertical control is visible and the healthy riparian corridor appears to be keeping the channel stable in the lateral sense. The rate of erosion is increasing at this site. Based on erosion measurements from aerial photographs the bank moved approximately 150 feet from 1972 to 1992 (7.5 feet per year), and from ground measurements approximately 125 feet from 1991 to April 1994 (39 feet per year). The streamside vegetation was just beginning to be breached on the 1972 aerial photographs. Since that time the erosion has progressed rapidly and is destroying the well-vegetated corridor downstream from this site. The upstream corridor is very dense and appears to be stable.


Photo 31: View downstream of the Calf Creek Site (1994).


Photo 32: View downstream of the Calf Creek Site (2000).

Project Description

Pre-project geomorphic cross sections (Appendix A) and planview survey of the project site was conducted. Six permanent survey monuments were installed in the field adjacent to the site and cross sections of the site were taken from each monument The bank was back-sloped to approximately a 1:1 slope and native river cane rhizomes were planted in the bank. A two row cedar tree revetment was installed (approximately 125 trees) along and above the toe covering 10 to12 feet of the 20 foot back-sloped bank. The cedar trees were anchored using #88 duck bill anchors and 3/16 inch cable. Native seedlings were planted using 8x8-foot spacing inside a 100-foot riparian buffer and along the top portion of the back-sloped bank. The revetment and rhizome planting portion of this project was completed in 1994, and the seedlings were planted in 1994, 1995, and1996.

Summary of Project Results

Overall Summary – Stabilization efforts at this site have completely failed along the lower two-thirds and upper third is unraveling. The lower half of the bank has eroded into the agricultural field an additional 60 feet. The thalweg is against the toe of the bank for it's entire length. The eroding bank is vertical with little or no vegetation. Only a 150 foot upper portion of the 500 foot revetment remains.

This site demonstrates a number of "don'ts" associated with installation of cedar revetments. It should be noted that for the first three-years of the revetment's life the bank was recovering quite well. The clay content of the soil and the amount of river cane we transplanted combined to produce a lush growth of vegetation on the bank. However, by the fourth year the cedars were beginning to decay and the negative aspects of this site began to rule. The combination of negative impacts include: 1.) relatively small radius of curvature and high erosion rate, 2.) ongoing substantial disturbances in the watershed (clearing of steep hillsides and riparian zones and in-stream dozing above the park), 3.) the fact that the thalweg remained against the bank. As a result, the point bar opposite the bank continued to accumulate sediment and the thalweg became narrower and ever more aggressive on the bank and even started to under-cut portions of the revetment. Eventually, a half-dozen trees in the lower revetment failed and the entire structure is unraveling due to cutting of the bank behind the lower trees and propagation of this cutting in the upstream direction.

Upper Third – This is the only portion of the revetment remaining with deposition covering about one third to one half of the cedar trees. There are hardwood seedlings and annual vegetation covering the bank on this portion except for the upper 30 feet, which has a six foot vertical face.

Middle and Lower Thirds – The cedar trees on this portion of the revetment are completely gone. The bank is exposed and eroding.

Grinders Ferry

River Mile: 57.9
Site Type: Valley Crossover, Massive Slumping
Bank Height: 20feet
Bank Length: 420 feet
Technique: Cedar tree revetment, streambank back-sloping and revegetation.

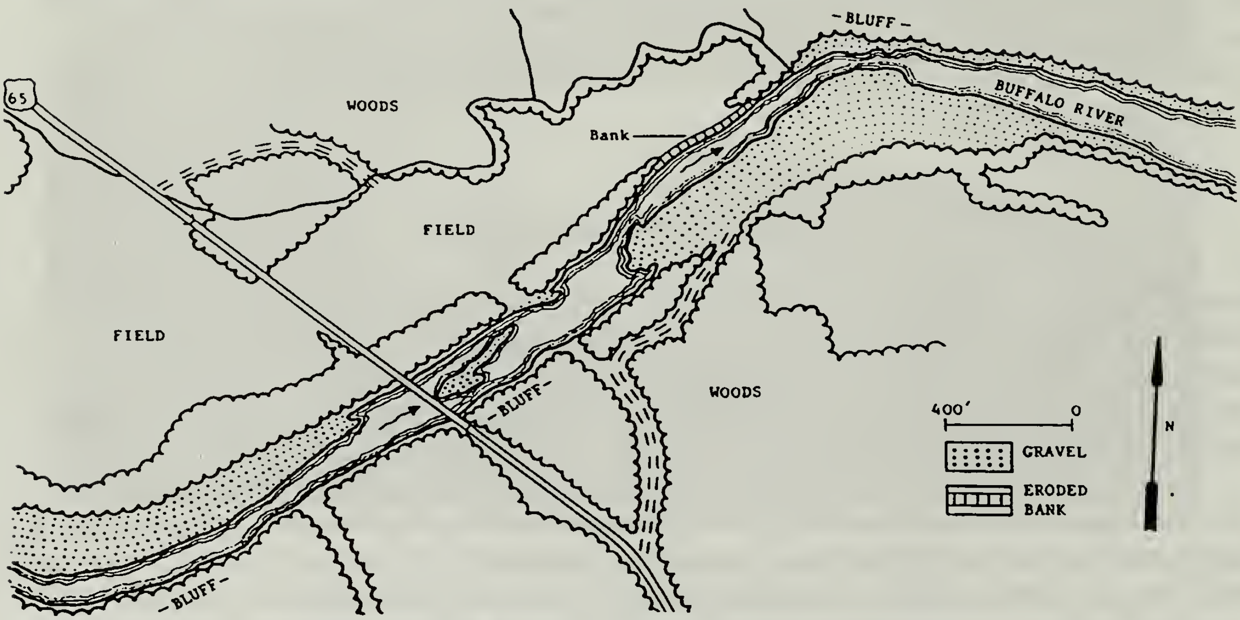


Figure 19: Planview sketch of the Grinders Ferry Site.

Pre-Project Site Description

This site is located on the main channel of the Buffalo River. The bank is approximately 20 feet high and 420 feet in length. This is a classic example of a too narrow corridor of streamside vegetation that slumped catastrophically. Fortunately, the streamside above this point is characterized by a gentle slope that will probably resist slumping although the buffer is too thin. The area of the bank that has slumped has no trees along it and thus will have a hard time revegetating due to the lack of seed sources and rill erosion and other factors constantly working on the naked bank. The area of buffer below the bank is too thin and fairly steep in profile. It is probably a good candidate for continued slumping. This bank failed catastrophically during a flood in 1991. Approximately 50 feet of the bank went all at once during this rapid rise and fall of the hydrograph. Ground based monitoring has only recently been implemented at this site. As with most of the river channel in the middle and lower river, the bed is composed of gravel with cobbles interspersed. The bank is composed of very unconsolidated silty sand, loose sand and minor layers of clayey sand. The channel has a very stable profile above the slump area. On the opposite side of the bank is a gravel bar that has some variable sized emergent vegetation such as willows and appears to be quite stable as viewed on the aerial photographs. Massive slumping was the dominant process and is probably going to occur again on the lower bank. The naked part of the bank is now being impacted by scour during high water and rill during heavy rains that can easily move the unconsolidated sand composing this bank. If these processes continue the bank will eventually develop a more vertical profile, become unstable when loaded with water, and the slumping process will be repeated.

Photo 33: View downstream of the Grinders Ferry Site. (1994)

Photo 34: View downstream of the Grinders Ferry Site (2000).

Project Description

A pre-project geomorphic cross section and planview survey of the project site was conducted. Six permanent survey monuments were installed in the field adjacent to the site and cross sections of the site were taken from four of the monuments. The bank was back-sloped to approximately a 1:1 slope and native river cane rhizomes were planted in the bank. A two row cedar tree revetment was installed (approximately 70 trees) along and above the toe covering 15 to 25 feet of the 40 foot back-sloped bank. The large cedar trees were anchored using #88 duck bill anchors and 3/16 inch cable. Native seedlings were planted using 8x8-foot spacing inside a 100-foot riparian buffer and along the top portion of the back-sloped bank. The revetment and rhizome planting portion of this project was completed in 1994 the seedlings were planted in 1994, 1995, and1996

Summary of Project Results

Overall Summary – The stabilization techniques used at this site have worked on the upper portion of the bank. The upper portion of the bank is stable and well vegetated with sycamores, willows and other natural vegetation. The thalweg has moved well away from the toe of the bank slope and a well vegetated point bar has formed on the upstream end of the project area. It is believed the stability of the upper end of the revetment will provide long term stability for the entire bank and allow natural processes to resume.

Several factors appear to be competing with recovery at this site: 1.) droughty soils 2.) unusual circumstances (tree) 3.) bedrock 4.) willows on opposite bank. This site is a good example of how, in the real hydrologic world, some things just can't be predicted. In this case, the sycamore trees pointed out in photos 23 and 24 are apparently rooted in a crack in bedrock. When the revetment was constructed it was assumed that the trees would be uprooted and washed away like so many other trees along the bank. However, instead of washing out they caught huge trees washing down the river and formed a large log jam. This obstruction, which was at times over 50 feet across, forced highly turbulent water into the lower end of the revetment, blew-out the lower trees, and caused 40 feet of the bank to retreat. It appears these sycamore trees are going to survive a trip across the Buffalo River! Lateral channel erosion is transporting them from river left trees to river right trees.

Upper Third – This portion of the revetment is totally covered with deposition. There are one and one-half inch sycamore trees growing out of the revetment and willows growing in and along the slope. As stated above, there is a well vegetated point bar that has formed in front of this portion of the revetment.

Middle and lower Thirds – The bank has slumped away from the revetment all along this portion of the project. The remaining cedar trees are fully exposed and in the water. The thalweg is well out away from the revetment.

South Maumee

River Mile: 40.5
Site Type: Massive Slump Zone and Overbank Scour
Bank Height: 30 to 35 feet
Bank Length: 800 feet
Technique: Cedar Revetment and riparian Corridor restoration

Figure 20: Planform sketch of the South Maumee Site.

Pre-Project Site Description

This site is located on the main channel of the Buffalo River down stream of the South Maumee access area. Bank height ranges from 30 to 35 feet and is 800 feet long. Aerial photos indicate 70 to 100 feet of bank have been removed between 1972 and 1992. The above and below stream-side forest is still in-tact but does not extend very far onto the flood plain. More slumping is likely as aggradation continues in the channel and more floods come down the river. One small clump of trees continues to cling to the top of the bank about 2/3 of the way down. The entire channel length visible from the top of the bank is underlain by solid bedrock. The bank is composed of very unconsolidated sand. The channel has a large bluff on the river left and this steep eroding bank on river right. A large gravel bar is forming in the river directly out from this bank that is nearly as long as the bank. On the 1972 aerial photographs it is obvious that the river had overtopped this bank during some relatively recent period of flooding and had scarred the flood plain and torn up the stream-side buffer much like has been observed more recently at Big Creek and the Sheldon Branch Field. This damage to the stream-side forest combined with the removal of the flood plain forest for agriculture probably set this bank up for ultimate slumping. It may be possible that some of the gravel bar formed in front of the bank is partially composed of material transported off the bank during the slumping episode.


Photo 35: View upstream of the South Maumee Site (1994).


Photo 36: View upstream of the South Maumee Site (2001).

Project Description

Due to the size and material on this bank no back-sloping was undertaken. A two row cedar tree revetment was installed (approximately 125 trees) along and above the toe covering 15 to 25 feet of the 800 foot bank. The cedar trees were anchored using #88, #138 duck bill anchors, and 3/16 inch cable. Native seedlings were planted using 8x8-foot spacing inside a 100-foot riparian buffer. The revetment portion of this project was completed in 1996. The seedlings were planted in 1994, 1995, and 1996.

Summary of project results

Overall Summary – Stabilization efforts at this site have been successful to a large extent. The cedar tree revetment constructed at this site has stabilized the upper 600 feet of the 800 foot eroding bank. Native vegetation is rebounding and assuming its natural role in stabilizing the bank. The summer willow planting effort here was not successful.

Upper Third – The majority of this portion of the revetment has held. A small portion of the upstream end has blown out below the existing healthy riparian corridor. Numerous sycamore trees and a few willows have established themselves in and around the revetment and on the bank toe. This portion of the revetment is totally filled with deposition.

Middle Third – This portion of the revetment is much like the upper third. There are two cedar trees missing from the upper end of the middle third. The revetment, in the middle third, is completely filled with deposition.

Lower Third – More than one half of the lower third is completely gone and continues to erode.

Photo 37: View looking upstream at lower portion of South Maumee Site (2001).

Section B

Site Assessment Questionnaire

Assessment Questionnaire Overview

This section is intended to provide an opportunity to use what we at Buffalo National River have learned about tree revetments and apply them to other potential stream-bank erosion sites. Almost anyone managing streams or lands with streams running through them will be confronted with an eroding stream bank sooner or later. The assessment questionnaire presented in this section was designed to provide a ready reference for the important questions that should be asked as a starting point in the decision making process. We have also provided a summary of how each question is important and have attempted to put the questions into the context of "good" and "bad" indicators. In order to simplify the results of the assessment questions, some of the yes and no answer blocks have been highlighted in gray. These "key indicators" can be used to score the results of the Assessment Questionnaire by adding the number of gray blocks checked. The more gray boxes that are checked for a particular bank the less likely a revetment will be effective on that bank. This is illustrated in the results of the assessment questionnaire filled out for banks treated at the Buffalo National River. The three banks with a score of six and higher partially or totally failed. The three banks with a score of two or less are primarily successful.

Blank Site Assessment Questionnaire

Assessment Questions	Y	N
1. The primary objective is to "stop" erosion?		
2. The primary objective is to restore natural processes?		
3. Can the impacts to bank or channel that caused the original or ongoing disturbance be stopped or alleviated?		
4. Is the thalweg against the eroding bank?		
5. Is any vegetation trying to colonize bank?		
6. Is any vegetation trying to colonize channel in front of bank?		
7. Can the bank be back-sloped?		
8. Can a natural buffer be established above the bank?		
9. Are appropriate type and size of trees available, and can they be practically transported to the bank?		
10. Is bank material dominated by sand or are there other factors such as aspect that would cause the bank to experience extreme drought?		
11. Will resources be available for inspection and maintenance?		
12. Is it possible to drive duckbill or other anchors into the toe of the bank?		
13. Is channel bottom on bedrock?		
14. Is bank rapidly eroding or is the radius of curvature small?		
15. Are there unique circumstances that might interfere with recovery?		
16. Is the channel down-cutting?		
17. Is the channel extensively over-widened?		
18. Is significant willow encroachment occurring within the channel opposite the bank?		
19. Is the water deeper in front of the bank than your equipment and personnel can operate in?		
20. Can the structure be tied into stable streambanks above and below the revetment?		
21. Is this a confluence site?		
22. Is there significant disturbance in the watershed above the site?		
Total number of gray blocks checked		

Considerations based on questions asked in the Assessment Questionnaire:

1.) If you answered yes, a cedar revetment is probably not appropriate. A properly constructed cedar revetment will stop erosion on almost any bank, for a while. Eventually though, the cedars will rot or other factors will compromise the structure. When that happens you will either need to repair or reconstruct the revetment, or, better yet, the natural vegetation will have returned to stabilize the bank. In either event, some erosion (hopefully at a natural rate) will continue to affect the bank. If, for example, there is some significant structure near the bank that must be protected at all costs and drives your primary objective toward "stopping" erosion, it must be realized that this is not what cedar revetments are intended to do. Perhaps a hard structure such as rock vanes, or more traditional bank protection such as rip-rap, should be considered.

2.) If you answered yes, you should seek the least expensive and most practical bioremediation technique shown to be successful in your area and on the type of stream and bank you are dealing with. Often cedar revetments fit this definition because they provide the temporary structural protection to the bank, buying time if you will, and allowing transplanted and/or volunteer vegetation to become established. Cedar revetments are strongly encouraged, even where there are other risks and probable future maintenance involved in eventually reaching the goal of a naturally functioning channel.

3.) If you answered no, a cedar revetment is probably not appropriate. Again, the primary use of bioremediation is to restore natural processes. This will probably not be possible if anthropogenic disturbances are ongoing.

4.) If you answered yes, your odds of long-term success are lower and the odds that you will have to perform future maintenance on the structure are higher. The reason for this is scour acting on and under the revetment in the vicinity of the high velocity thalweg. However, this does not mean that cedar revetments should not be used, but this is an important consideration to combine with other considerations expressed below.

5.) If you answered yes to this question you can view this as a good sign. Especially if the vegetation is older than the previous flood season. In essence, bank vegetation is indicative of a stream-bank that is trying to stabilize on its own, but needs a little help. You will have to decide if the bank will stabilize on its own once the disturbance is removed, or whether intervention, such as a cedar revetment, will be needed to assist the restoration.

6.) Same thought process as in number 5.

7.) If the answer to this is no, the restoration process will be hindered because re-vegetation will be difficult or almost impossible on the very steep or vertical portions of the bank. However, where other conditions are favorable, back-sloping is not mandatory.

8.) If the answer to this is no, much of the benefits of restoring a natural riparian buffer zone will be lost. These benefits include long-term bank stability.

9.) If the answer to this is no, then a cedar (or other type of tree) revetment is not practical. Even if trees are available, it is important to remember that in most cases much of the effort involved in constructing revetments is transporting the trees to the site. Bushy cedar trees are hard to handle where they must be loaded on a trailer and transported over the road.

10.) If the answer to this is yes, you can expect to have significant trouble restoring a vigorous growth of vegetation on the bank. Recurrent watering and soil remediation may be needed which will add significantly to the overall cost of the project.

11.) If the answer to this is no, your chances of long-term success at a given bank are reduced as a function of the other negative aspects associated with the site. In other words, if the bank just needs a little nudge to begin the restoration process, maintenance will probably not be needed. In other cases where several negative factors are impacting the bank and the revetment will take obvious stress, inspection and maintenance becomes very important.

12.) If the answer to this is no, a cedar revetment will be difficult if not impossible to construct. The most common reason for trouble with installing duckbills is cobble in the lower portion of the bank often found in high-energy stream systems. This can be overcome by such approaches as pre-drilling the anchor holes with a pneumatic hammer or drill, but this is extremely labor intensive and increases time and expense.

13.) If the answer to this is yes, the stream will probably be more aggressive than otherwise in stressing the bank. This is because there is no opportunity for the channel to adjust in the vertical dimension (unless the channel aggrades) and its erosional forces must be expended in the horizontal dimension.

14.) If the answer to either of these questions is yes, and especially if the answer to both of these questions is yes, your odds of restoring natural bank stability similar to a stable reach somewhere else on the stream are greatly reduced. One of the guiding principles of bioremediation is that these efforts serve to give the bank that little bit of push needed to allow native vegetation to return over time and serve its natural role of bank stability. If the bank is rapidly eroding (five feet per year or greater) or the radius of curvature is small (i.e. less than the radius of curvature of other stable reaches), the erosional forces acting on the bank will, in most cases and in fairly short order, tear out the revetment. If the will is there, the revetment can be maintained after major flood events and erosion can be greatly reduced. However, when the maintenance stops, high rates of erosion will likely return.

15.) This is one of the hardest questions to answer. Unique circumstances might include bridges near the reach, lone trees in the channel or near the bank which could catch debris and deflect currents into the bank, heavy elk, beaver, or other wildlife browsing and trampling, or something else which may be unique to your area.

16.) If the answer to this is yes, your revetment may be undermined.

17.) If the answer to this is yes, there is a good chance that one or more sediment bars may form within the channel. If these bars then become stabilized by vegetation they can deflect flow and the thalweg toward the bank and destabilize the revetment. This has been observed at prior gravel mining sites, for example. Inclusion of natural channel design principles is probably applicable to restoration at such sites.

18.) If the answer to this is yes, the hydraulic roughness and durability of willows should not be underestimated. Where they can be incorporated into the bioremediation of the eroding bank they are a tremendous asset. Where willows are encroaching on the channel from the other side, they can force flood waters and the thalweg to be redirected toward the opposite bank. This was only observed to be a major factor at the over-widened gravel mining site.

19.) If the answer to this question is yes, revetment construction is probably not practical. The bank can be worked from the top but this is much more difficult than having access above and below. Coffer dam systems can also be utilized but the expense and labor usually exceeds what can be afforded.

20.) If the answer to this is no, the revetment will be in jeopardy of erosion working in behind the revetment from above or below.

21.) Confluence sites are inherently more unstable due to back-watering from the main channel and assorted chaotic sediment transport through these reaches.

22.) Watershed disturbance can increase both flood magnitude and sediment loads. Both of these factors can favor bank erosion and channel adjustments. Which can over power the protective function of the cedar branches.

Luallen Site
Assessment Questionnaire

Assessment Questions	Y	N
1. The primary objective is to "stop" erosion?		X
2. The primary objective is to restore natural processes?	X	
3. Can the impacts to bank or channel that caused the original or ongoing disturbance be stopped or alleviated?	X	
4. Is the thalweg against the eroding bank?		X
5. Is any vegetation trying to colonize bank?		X
6. Is any vegetation trying to colonize channel in front of bank?		X
7. Can the bank be back-sloped?	X	
8. Can a natural buffer be established above the bank?	X	
9. Are appropriate type and size of trees available, and can they be practically transported to the bank?	X	
10. Is bank material dominated by sand or are there other factors such as aspect that would cause the bank to experience extreme drought?		X
11. Will resources be available for inspection and maintenance?	X	
12. Is it possible to drive duckbill or other anchors into the toe of the bank?	X	
13. Is channel bottom on bedrock?		X
14. Is bank rapidly eroding or is the radius of curvature small?		X
15. Are there unique circumstances that might interfere with recovery?		X
16. Is the channel down-cutting?		X
17. Is the channel extensively over-widened?	X	
18. Is significant willow encroachment occurring within the channel opposite the bank?	X	
19. Is the water deeper in front of the bank than your equipment and personnel can operate in?		X
20. Can the structure be tied into stable streambanks above and below the revetment?	X	
21. Is this a confluence site?		X
22. Is there significant disturbance in the watershed above the site?		X
Total number of gray blocks checked	4	

Comments: 17.) Site has been over-widened by past gravel mining. 18.) Willows are thick and extensive on the opposite bank, and a new flood plain is trying to develop across the channel.

Beech Creek
Assessment Questionnaire

Assessment Questions	**Y**	**N**
1. The primary objective is to "stop" erosion?		X
2. The primary objective is to restore natural processes?	X	
3. Can the impacts to bank or channel that caused the original or ongoing disturbance be stopped or alleviated?	X	
4. Is the thalweg against the eroding bank?		X
5. Is any vegetation trying to colonize bank?	X	
6. Is any vegetation trying to colonize channel in front of bank?		X
7. Can the bank be back-sloped?	X	
8. Can a natural buffer be established above the bank?	X	
9. Are appropriate type and size of trees available, and can they be practically transported to the bank?	X	
10. Is bank material dominated by sand or are there other factors such as aspect that would cause the bank to experience extreme drought?		X
11. Will resources be available for inspection and maintenance?	X	
12. Is it possible to drive duckbill or other anchors into the toe of the bank?		X
13. Is channel bottom on bedrock?	X	
14. Is bank rapidly eroding or is the radius of curvature small?		X
15. Are there unique circumstances that might interfere with recovery?		X
16. Is the channel down-cutting?		X
17. Is the channel extensively over-widened?		X
18. Is significant willow encroachment occurring within the channel opposite the bank?		X
19. Is the water deeper in front of the bank than your equipment and personnel can operate in?		X
20. Can the structure be tied into stable streambanks above and below the revetment?	X	
21. Is this a confluence site?		X
22. Is there significant disturbance in the watershed above the site?		X
Total number of gray blocks checked	3	

Ferguson
Assessment Questionnaire

Assessment Questions	**Y**	**N**
1. The primary objective is to "stop" erosion?		X
2. The primary objective is to restore natural processes?	X	
3. Can the impacts to bank or channel that caused the original or ongoing disturbance be stopped or alleviated?	X	
4. Is the thalweg against the eroding bank?	*	
5. Is any vegetation trying to colonize bank?		X
6. Is any vegetation trying to colonize channel in front of bank?		X
7. Can the bank be back-sloped?	X	
8. Can a natural buffer be established above the bank?	X	
9. Are appropriate type and size of trees available, and can they be practically transported to the bank?	X	
10. Is bank material dominated by sand or are there other factors such as aspect that would cause the bank to experience extreme drought?		X
11. Will resources be available for inspection and maintenance?	X	
12. Is it possible to drive duckbill or other anchors into the toe of the bank?	X	
13. Is channel bottom on bedrock?		X
14. Is bank rapidly eroding or is the radius of curvature small?		X
15. Are there unique circumstances that might interfere with recovery?		X
16. Is the channel down-cutting?		X
17. Is the channel extensively over-widened?	X	
18. Is significant willow encroachment occurring within the channel opposite the bank?		X
19. Is the water deeper in front of the bank than your equipment and personnel can operate in?		X
20. Can the structure be tied into stable streambanks above and below the revetment?	X	
21. Is this a confluence site?		X
22. Is there significant disturbance in the watershed above the site?		X
Total number of gray blocks checked	4	

Comments: *4. Yes, on the upper half.

Cecil Creek
Assessment Questionnaire

Assessment Questions	Y	N
1. The primary objective is to "stop" erosion?		X
2. The primary objective is to restore natural processes?	X	
3. Can the impacts to bank or channel that caused the original or ongoing disturbance be stopped or alleviated?	X	
4. Is the thalweg against the eroding bank?	X	
5. Is any vegetation trying to colonize bank?	X	
6. Is any vegetation trying to colonize channel in front of bank?		X
7. Can the bank be back-sloped?		X
8. Can a natural buffer be established above the bank?	X	
9. Are appropriate type and size of trees available, and can they be practically transported to the bank?	X	
10. Is bank material dominated by sand or are there other factors such as aspect that would cause the bank to experience extreme drought?		X
11. Will resources be available for inspection and maintenance?	X	
12. Is it possible to drive duckbill or other anchors into the toe of the bank?	X	
13. Is channel bottom on bedrock?		X
14. Is bank rapidly eroding or is the radius of curvature small?		X
15. Are there unique circumstances that might interfere with recovery?		X
16. Is the channel down-cutting?		X
17. Is the channel extensively over-widened?		X
18. Is significant willow encroachment occurring within the channel opposite the bank?		X
19. Is the water deeper in front of the bank than your equipment and personnel can operate in?		X
20. Can the structure be tied into stable streambanks above and below the revetment?	X	
21. Is this a confluence site?	X	
22. Is there significant disturbance in the watershed above the site?		X
Total number of gray blocks checked	**4**	

Angle Field
Assessment Questionnaire

Assessment Questions	Y	N
1. The primary objective is to "stop" erosion?		X
2. The primary objective is to restore natural processes?	X	
3. Can the impacts to bank or channel that caused the original or ongoing disturbance be stopped or alleviated?	X	
4. Is the thalweg against the eroding bank?		X
5. Is any vegetation trying to colonize bank?	X	
6. Is any vegetation trying to colonize channel in front of bank?		X
7. Can the bank be back-sloped?	X	
8. Can a natural buffer be established above the bank?	X	
9. Are appropriate type and size of trees available, and can they be practically transported to the bank?	X	
10. Is bank material dominated by sand or are there other factors such as aspect that would cause the bank to experience extreme drought?	X	
11. Will resources be available for inspection and maintenance?	X	
12. Is it possible to drive duckbill or other anchors into the toe of the bank?	X	
13. Is channel bottom on bedrock?		X
14. Is bank rapidly eroding or is the radius of curvature small?		X
15. Are there unique circumstances that might interfere with recovery?		X
16. Is the channel down-cutting?		X
17. Is the channel extensively over-widened?		X
18. Is significant willow encroachment occurring within the channel opposite the bank?		X
19. Is the water deeper in front of the bank than your equipment and personnel can operate in?		X
20. Can the structure be tied into stable streambanks above and below the revetment?	X	
21. Is this a confluence site?		X
22. Is there significant disturbance in the watershed above the site?		X
Total number of gray boxes checked	2	

Comments: 5. Upper and lower portions have some sparse vegetation.

Upper Rock Creek
Assessment Questionnaire

Assessment Questions	**Y**	**N**
1. The primary objective is to "stop" erosion?		X
2. The primary objective is to restore natural processes?	X	
3. Can the impacts to bank or channel that caused the original or ongoing disturbance be stopped or alleviated?	X	
4. Is the thalweg against the eroding bank?	X	
5. Is any vegetation trying to colonize bank?		X
6. Is any vegetation trying to colonize channel in front of bank?		X
7. Can the bank be back-sloped?	X	
8. Can a natural buffer be established above the bank?	X	
9. Are appropriate type and size of trees available, and can they be practically transported to the bank?	X	
10. Is bank material dominated by sand or are there other factors such as aspect that would cause the bank to experience extreme drought?		X
11. Will resources be available for inspection and maintenance?	X	
12. Is it possible to drive duckbill or other anchors into the toe of the bank?	X	
13. Is channel bottom on bedrock?		X
14. Is bank rapidly eroding or is the radius of curvature small?		X
15. Are there unique circumstances that might interfere with recovery?		X
16. Is the channel down-cutting?		X
17. Is the channel extensively over-widened?		X
18. Is significant willow encroachment occurring within the channel opposite the bank?		X
19. Is the water deeper in front of the bank than your equipment and personnel can operate in?		X
20. Can the structure be tied into stable streambanks above and below the revetment?	X	
21. Is this a confluence site?		X
22. Is there significant disturbance in the watershed above the site?		X
Total number of gray blocks checked	3	

Lower Rock Creek
Assessment Questionnaire

Assessment Questions	**Y**	**N**
1. The primary objective is to "stop" erosion?		X
2. The primary objective is to restore natural processes?	X	
3. Can the impacts to bank or channel that caused the original or ongoing disturbance be stopped or alleviated?	X	
4. Is the thalweg against the eroding bank?	X	
5. Is any vegetation trying to colonize bank?		X
6. Is any vegetation trying to colonize channel in front of bank?		X
7. Can the bank be back-sloped?	X	
8. Can a natural buffer be established above the bank?	X	
9. Are appropriate type and size of trees available, and can they be practically transported to the bank?	X	
10. Is bank material dominated by sand or are there other factors such as aspect that would cause the bank to experience extreme drought?	X	
11. Will resources be available for inspection and maintenance?	X	
12. Is it possible to drive duckbill or other anchors into the toe of the bank?	X	
13. Is channel bottom on bedrock?		X
14. Is bank rapidly eroding or is the radius of curvature small?		X
15. Are there unique circumstances that might interfere with recovery?		X
16. Is the channel down-cutting?		X
17. Is the channel extensively over-widened?		X
18. Is significant willow encroachment occurring within the channel opposite the bank?		X
19. Is the water deeper in front of the bank than your equipment and personnel can operate in?		X
20. Can the structure be tied into stable streambanks above and below the revetment?	X	
21. Is this a confluence site?	X	
22. Is there significant disturbance in the watershed above the site?		X
Total number of gray blocks checked	**5**	

Sheldon Branch
Assessment Questionnaire

Assessment Questions	**Y**	**N**
1. The primary objective is to "stop" erosion?		X
2. The primary objective is to restore natural processes?	X	
3. Can the impacts to bank or channel that caused the original or ongoing disturbance be stopped or alleviated?	X	
4. Is the thalweg against the eroding bank?		X
5. Is any vegetation trying to colonize bank?	X	
6. Is any vegetation trying to colonize channel in front of bank?	X	
7. Can the bank be back-sloped?	X	
8. Can a natural buffer be established above the bank?	X	
9. Are appropriate type and size of trees available, and can they be practically transported to the bank?	X	
10. Is bank material dominated by sand or are there other factors such as aspect that would cause the bank to experience extreme drought?		X
11. Will resources be available for inspection and maintenance?	X	
12. Is it possible to drive duckbill or other anchors into the toe of the bank?	X	
13. Is channel bottom on bedrock?		X
14. Is bank rapidly eroding or is the radius of curvature small?		X
15. Are there unique circumstances that might interfere with recovery?		X
16. Is the channel down-cutting?		X
17. Is the channel extensively over-widened?		X
18. Is significant willow encroachment occurring within the channel opposite the bank?		X
19. Is the water deeper in front of the bank than your equipment and personnel can operate in?		X
20. Can the structure be tied into stable streambanks above and below the revetment?	X	
21. Is this a confluence site?		X
22. Is there significant disturbance in the watershed above the site?		X
Total number of gray blocks checked	0	

Jamison Creek
Assessment Questionnaire

Assessment Questions	**Y**	**N**
1. The primary objective is to "stop" erosion?		X
2. The primary objective is to restore natural processes?	X	
3. Can the impacts to bank or channel that caused the original or ongoing disturbance be stopped or alleviated?	X	
4. Is the thalweg against the eroding bank?		*
5. Is any vegetation trying to colonize bank?		X
6. Is any vegetation trying to colonize channel in front of bank?		X
7. Can the bank be back-sloped?	X	
8. Can a natural buffer be established above the bank?	X	
9. Are appropriate type and size of trees available, and can they be practically transported to the bank?	X	
10. Is bank material dominated by sand or are there other factors such as aspect that would cause the bank to experience extreme drought?		X
11. Will resources be available for inspection and maintenance?	X	
12. Is it possible to drive duckbill or other anchors into the toe of the bank?	X	
13. Is channel bottom on bedrock?		X
14. Is bank rapidly eroding or is the radius of curvature small?		X
15. Are there unique circumstances that might interfere with recovery?		X
16. Is the channel down-cutting?		X
17. Is the channel extensively over-widened?		X
18. Is significant willow encroachment occurring within the channel opposite the bank?		X
19. Is the water deeper in front of the bank than your equipment and personnel can operate in?		X
20. Can the structure be tied into stable streambanks above and below the revetment?		X
21. Is this a confluence site?		X
22. Is there significant disturbance in the watershed above the site?		X
Total number of gray blocks checked	3	

Comments: *4. Not exactly against the bank – could possibly modify, but this bank consistently takes high velocity flows in high water and is on the outside of a wide bend

Baker Ford
Assessment Questionnaire

Assessment Questions	**Y**	**N**
1. The primary objective is to "stop" erosion?		X
2. The primary objective is to restore natural processes?	X	
3. Can the impacts to bank or channel that caused the original or ongoing disturbance be stopped or alleviated?	X	
4. Is the thalweg against the eroding bank?		X
5. Is any vegetation trying to colonize bank?	X	
6. Is any vegetation trying to colonize channel in front of bank?	X	
7. Can the bank be back-sloped?		X
8. Can a natural buffer be established above the bank?	X	
9. Are appropriate type and size of trees available, and can they be practically transported to the bank?	X	
10. Is bank material dominated by sand or are there other factors such as aspect that would cause the bank to experience extreme drought?	X	
11. Will resources be available for inspection and maintenance?	X	
12. Is it possible to drive duckbill or other anchors into the toe of the bank?	X	
13. Is channel bottom on bedrock?		X
14. Is bank rapidly eroding or is the radius of curvature small?		X
15. Are there unique circumstances that might interfere with recovery?		X
16. Is the channel down-cutting?		X
17. Is the channel extensively over-widened?		X
18. Is significant willow encroachment occurring within the channel opposite the bank?		X
19. Is the water deeper in front of the bank than your equipment and personnel can operate in?		X
20. Can the structure be tied into stable streambanks above and below the revetment?	X	
21. Is this a confluence site?		X
22. Is there significant disturbance in the watershed above the site?		X
Total number of gray blocks checked	2	

Calf Creek
Assessment Questionnaire

Assessment Questions	Y	N
1. The primary objective is to "stop" erosion?		X
2. The primary objective is to restore natural processes?	X	
3. Can the impacts to bank or channel that caused the original or ongoing disturbance be stopped or alleviated?	X	
4. Is the thalweg against the eroding bank?	X	
5. Is any vegetation trying to colonize bank?		X
6. Is any vegetation trying to colonize channel in front of bank?		X
7. Can the bank be back-sloped?	X	
8. Can a natural buffer be established above the bank?	X	
9. Are appropriate type and size of trees available, and can they be practically transported to the bank?	X	
10. Is bank material dominated by sand or are there other factors such as aspect that would cause the bank to experience extreme drought?		X
11. Will resources be available for inspection and maintenance?	X	
12. Is it possible to drive duckbill or other anchors into the toe of the bank?	X	
13. Is channel bottom on bedrock?		X
14. Is bank rapidly eroding or is the radius of curvature small?	X	
15. Are there unique circumstances that might interfere with recovery?	*	
16. Is the channel down-cutting?		X
17. Is the channel extensively over-widened?		X
18. Is significant willow encroachment occurring within the channel opposite the bank?		X
19. Is the water deeper in front of the bank than your equipment and personnel can operate in?		X
20. Can the structure be tied into stable streambanks above and below the revetment?		X
21. Is this a confluence site?	X	
22. Is there significant disturbance in the watershed above the site?	X	
Total number of gray blocks checked	7	

Comments: 15.) The watershed above the site is disturbed and producing excessive sediment. Also the confluence and backwater factors have combined to make bedload transport processes insufficient to transport the sediment load.

Grinders Ferry
Assessment Questionnaire

Assessment Questions	**Y**	**N**
1. The primary objective is to "stop" erosion?		X
2. The primary objective is to restore natural processes?	X	
3. Can the impacts to bank or channel that caused the original or ongoing disturbance be stopped or alleviated?	X	
4. Is the thalweg against the eroding bank?	X	
5. Is any vegetation trying to colonize bank?		X
6. Is any vegetation trying to colonize channel in front of bank?		X
7. Can the bank be back-sloped?	X	
8. Can a natural buffer be established above the bank?	X	
9. Are appropriate type and size of trees available, and can they be practically transported to the bank?	X	
10. Is bank material dominated by sand or are there other factors such as aspect that would cause the bank to experience extreme drought?	X	
11. Will resources be available for inspection and maintenance?	X	
12. Is it possible to drive duckbill or other anchors into the toe of the bank?	X	
13. Is channel bottom on bedrock?	X	
14. Is bank rapidly eroding or is the radius of curvature small?		X
15. Are there unique circumstances that might interfere with recovery?	X	
16. Is the channel down-cutting?		X
17. Is the channel extensively over-widened?		X
18. Is significant willow encroachment occurring within the channel opposite the bank?	X	
19. Is the water deeper in front of the bank than your equipment and personnel can operate in?		X
20. Can the structure be tied into stable streambanks above and below the revetment?	X	
21. Is this a confluence site?		X
22. Is there significant disturbance in the watershed above the site?		X
Total number of gray blocks checked	7	

South Maumee
Assessment Questionnaire

Assessment Questions	Y	N
1. The primary objective is to "stop" erosion?		X
2. The primary objective is to restore natural processes?	X	
3. Can the impacts to bank or channel that caused the original or ongoing disturbance be stopped or alleviated?	X	
4. Is the thalweg against the eroding bank?		X
5. Is any vegetation trying to colonize bank?		X
6. Is any vegetation trying to colonize channel in front of bank?		X
7. Can the bank be back-sloped?		X
8. Can a natural buffer be established above the bank?	X	
9. Are appropriate type and size of trees available, and can they be practically transported to the bank?	X	
10. Is bank material dominated by sand or are there other factors such as aspect that would cause the bank to experience extreme drought?	X	
11. Will resources be available for inspection and maintenance?	X	
12. Is it possible to drive duckbill or other anchors into the toe of the bank?	X	
13. Is channel bottom on bedrock?	X	
14. Is bank rapidly eroding or is the radius of curvature small?		X
15. Are there unique circumstances that might interfere with recovery?	X	
16. Is the channel down-cutting?		X
17. Is the channel extensively over-widened?		X
18. Is significant willow encroachment occurring within the channel opposite the bank?		X
19. Is the water deeper in front of the bank than your equipment and personnel can operate in?		X
20. Can the structure be tied into stable streambanks above and below the revetment?	X	
21. Is this a confluence site?		X
22. Is there significant disturbance in the watershed above the site?		X
Total number of gray blocks checked	6	

Section C

Assessment of Riparian Restoration Sites

Methodology

Riparian buffer restoration efforts were evaluated by sampling 20' by 20' plots at 23 of the 29 restoration sites (Table 1) and by visual inspection of the remaining sites. Each plot was located 100 feet apart with the first plot located 100 feet from the downstream end of the buffer. The buffer width was measured at each 100' interval. The buffer width was the distance from the edge of the hay field or pasture to the top of the bank. A random number 0-9 was then drawn to determine where in the buffer width to place the 20' by 20' plot. The number drawn multiplied by ten was the percent distance of the buffer width to move out from the bank. From this point the plot was measured as 20 feet out from the bank and 20 feet downstream. On sites with low buffer widths the higher numbers were removed from the drawing so the plot selection was not biased toward the outer areas.

After the plot location was determined, each woody species in the area was counted and identified to species if possible. Pin oaks and shumard oaks were grouped together because of their similarities. Average heights of each species were also noted as well as the relative abundance of rivercane.

Twenty-three of the 29 sites were sampled. Sites 6, 9, 12, 24 and 29 were not sampled due to location and access problems. Sites 15 and 22 were not sampled because the buffer area was eroded.

The survival of the planted tree species was estimated by comparing the total number of seedlings planted and the number of those species present at all the sites. Since all sites were not sampled, seedlings planted at sites that were not sampled were not included in the total. The sites not sampled included approximately 13.5 % of the total acres planted. This percentage was subtracted from each species to determine how many trees were planted at the sampled sites. Random planting of trees across sites was assumed for this method.

Assessment Results

The total number of each tree species sampled showed that most of the planted species occurred at the rate of 150 to 250 trees per acre (Figure 1). Sweet gums occurred at a lower number but there were approximately one third as many planted. The volunteer species included locust, sycamore, and elm, which occurred at the majority of the sites. The trees in the "other" category included persimmon, sumac, and boxelder that occurred in relatively high numbers but were present at only a few sites. Eastern red cedar and silver maple were present at most sites but in low numbers.

Seedling survival (Figure 22) was relatively the same for all species. Green ash is shown to have a higher survival rate than other species but this may be inaccurate due to identification problems during some portions of the sampling. Walnut had the second highest survival rate at 40% and pin oak the lowest survival percentage at 27%. The overall survival rate for the planted seedlings was 40.6%. In general it appears that there was no overwhelmingly dominant species in terms of either survival or mortality

Numbers of seedlings for both planted and volunteer species in each plot were totaled. The plots at each site were averaged. The average number of seedlings per plot was then multiplied by 108.9 to convert the 20' by 20' plot to one acre. The number of seedlings per acre was determined for each site that could be sampled (Figure 3). Of the 23 sites sampled, 14 had 1,000 seedlings per acre or more and 3 contained between 1,500 and 2,000 per acre. Sites in the Boxley area contained the highest counts with the exception of site 10 which is discussed below.

The number of seedlings in a plot at each site was also examined in order to determine if the entire site has been successfully revegetated, or if gaps were present. The seedlings per acre at each site is also beneficial for this purpose but can be misleading due to concentrated areas of invasive volunteer species in some portions of the buffer while other portions have only planted seedling species.

The goal of the seedling plantings is to have 5 or more planted seedlings or volunteer seedlings in each 20' by 20' plot (500 per acre) that was sampled. The plots at each site were separated into those with 4 or less and those with 5 or more. Figure 4 in combination with Figure 3 was used to determine how each site is recovering on a plot by plot basis. It also shows what sites need to be replanted and the relative amount of replanting to be done at each site to meet our overall goal.

Three sites have a high percentage of plots with 4 or less seedlings and fall below the 500 seedlings per acre goal (#10 Running Creek, #13 Cecil Creek-upper, and #27 Calf Creek). There are a number of issues involved in seedling survival/mortality: planting methods and times are critical as are seedling transportation and storage, but the quality of the planting site, ungulate damage, and loss of a portion of riparian buffer due to erosion or mowing appear to be the largest contributing factors effecting survival rates. Poor seedling survival at the Running Creek site is most likely due to periodic inundation and the poor rocky soils. Cecil Creek-upper, has silty sand soil that does not hold moisture well and mowing of the hay field adjacent to the site has intruded into the buffer reducing it in size. The area is also frequented by elk that damage and kill the seedlings even after they have survived for a year or more. Calf Creek has very sandy silt soil that does not hold moisture well and the riparian buffer has been reduced considerably in size by erosion and mowing of the adjacent hay field.

Sites #14 Cecil Creek-lower and #29 South Maumee meet the 500 seedlings per acre goal but have a majority of plots with 4 or less seedlings per acre, indicating patchy conditions. Seedling survival at the Cecil Creek-lower site is reduced by the dense growth of native river cane encroaching on the riparian buffer. The South Maumee site has very sandy soils and seedlings here can not survive extended dry periods. The buffer has also been reduced in size by mowing of the adjacent hay field.

The total number of each species present (Figure 5) was determined by combining all the plots at all sites sampled. All species of planted trees were separated with the exception of shumard oak, which was grouped with the pin oak for ease in identification. The volunteer species were grouped together as “others” when they occurred at less than three sites, occurred in low numbers, or were unknown. Some of the species in this category include boxelder, persimmon, sumac, maple, and cedar. Each species present at the site was then graphed as a percent of the total at the site. All the volunteer species were grouped together. The resulting graph indicates the diversity of each site as well as what species dominated. It also indicates the abundance of volunteer species for a site.

The relative abundance of each species composition varied among the sites. Some sites were dominated by one species more than others, but most sites were diverse in both planted and volunteer species. No clear patterns of dominance by a species or low diversity occurred at the sampled sites.

Summary

There were 113,316 seedlings planted in 1995, 1996, and 1997 at the 23 sites assessed. A total of 60 acres of riparian buffer was planted amounting to 1,834 seedlings per acre. The overall survival rate for the seedlings planted is 40.6%. All of the 6 species (walnut, sweet gum, green ash, red oak, white oak, pin and shumard oak) planted had comparable survival rates. Volunteer species (boxelder, persimmon, sumac, maple, red cedar, locust, sycamore, elm) have contributed greatly to revegetation at the majority of the sites. Twenty sites have well above the minimum target number of 500 seedlings per acre, and 14 have more than 1,000 seedlings per acre. Soil moisture retention, mowing inside the buffer zone, ungulate damage, and erosion are the factors indicated as being responsible for the 3 sites which fell below the 500 seedlings per acre target. Although most sites have an adequate number of seedlings per acre there are areas inside the riparian buffers that have 4 or less seedlings inside the 20’ X 20’sample plot areas. Funding will be sought to purchase and plant seedlings to fill these “gaps” in the riparian buffers.

PLANTING SITE	AREA	ACRES	LOCATION
1. Luallen-upper	Boxley	1.9	T15N,R23W,Sec 22
2. Luallen-lower	Boxley	2.0	T15N,R23W,Sec 22
3. Fowler	Boxley	0.3	T15N,R23W,Sec 15
4. Beech Creek	Boxley	2.0	T15N,R23W,Sec 10
5. Clarks	Boxley	4	T15N,R23W,Sec 10
6. Arrington Creek	Boxley	3.4	T15N,R23W.Sec 11
7. Fergusions	Boxley	1.3	T15N,R23W.Sec 35
8. Villines-upper	Boxley	2.2	T16N,R23W,Sec 36
9. Villines-lower	Boxley	0.5	T16N,R23W,Sec 36
10. Running Creek	Boxley	0.5	T16N,R23W,Sec 36
11. Steel creek-upper	Boxley	1.4	T16N,R22W,Sec 18
12. Steel Creek-lower	Boxley	0.7	T16N,R22W,Sec 17
13. Cecil Creek-upper	Erbie	0.2	T17N,R21W,Sec 32
14. Cecil Creek-lower	Erbie	0.5	T17N,R21W,Sec 33
15. Jasper in June`	Erbie	1.1	T16N,R21W,Sec 5
16. Angle Field	Erbie	1.0	T16N,R21W,Sec 10
17. Rock Creek-upper	Hasty	0.4	T16N,R20W,Sec 34
18. Rock Creek-lower	Hasty	0.3	T16N,R20W,Sec 34
19. Sheldon Branch-upper	Hasty	1.4	T16N,R20W,Sec 35
20. Sheldon Branch-lower	Hasty	0.7	T16N,R20W,Sec 35
21. Big Creek-upper	Carver	1.0	T15N,R19W,Sec 6
22. Big Creek-lower	Carver	0.9	T15N,R19W,Sec 6
23. Jamison Creek	Woolum	20.0	T15N,R18W,Sec 2
24. Arnold Bend	Tyler Bend	4.5	T16N,R17W,Sec33
25. Arnold-lower	Tyler Bend	2.3	T16N,R17W,Sec34
26. Calf Creek Confluence	Tyler Bend	1.0	T15N,R17W,Sec 3
27. Calf Creek	Tyler Bend	1.0	T15N,R17W,Sec 3
28. Grinders Ferry	Tyler Bend	1.5	T16N,R17W,Sec36
29. South maumee	Maumee	2.0	T16N,R16W,Sec 12

Table 1: Riparian areas planted as part of restoration activities.

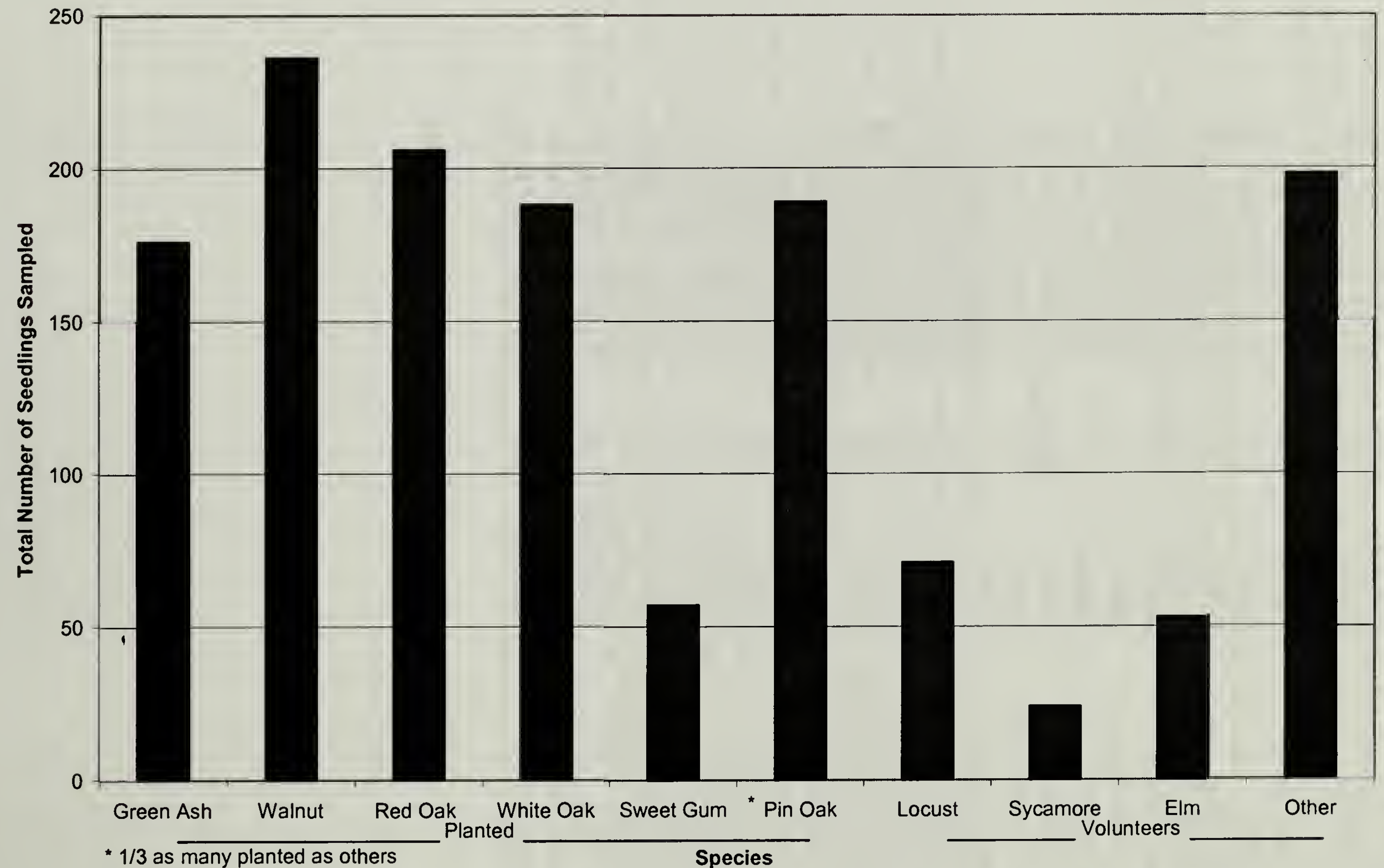


Figure 21: Planted and volunteer species in the 149 sample plots at 23 buffer sites.

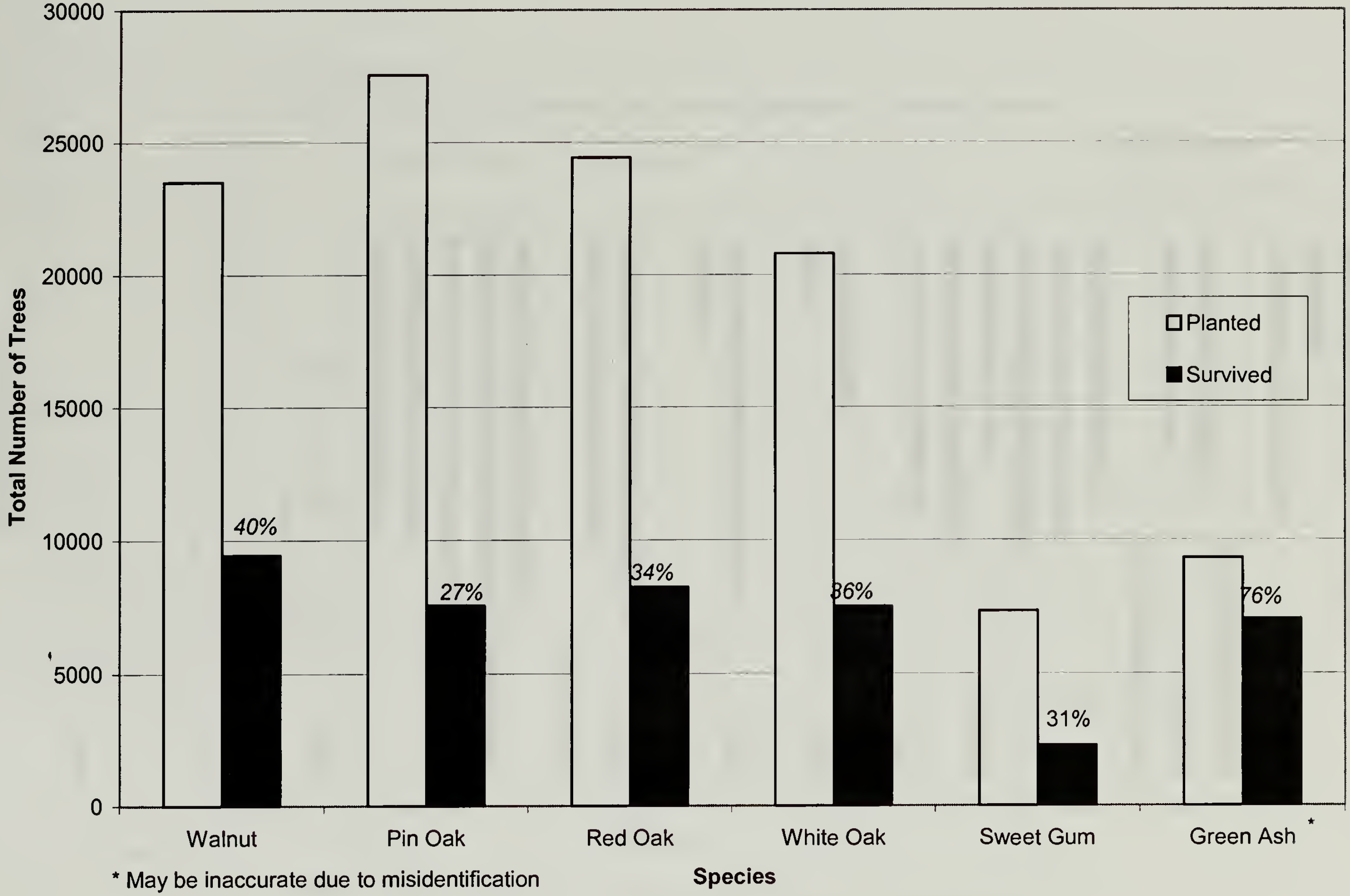


Figure 22: Seedling Survival by Species.

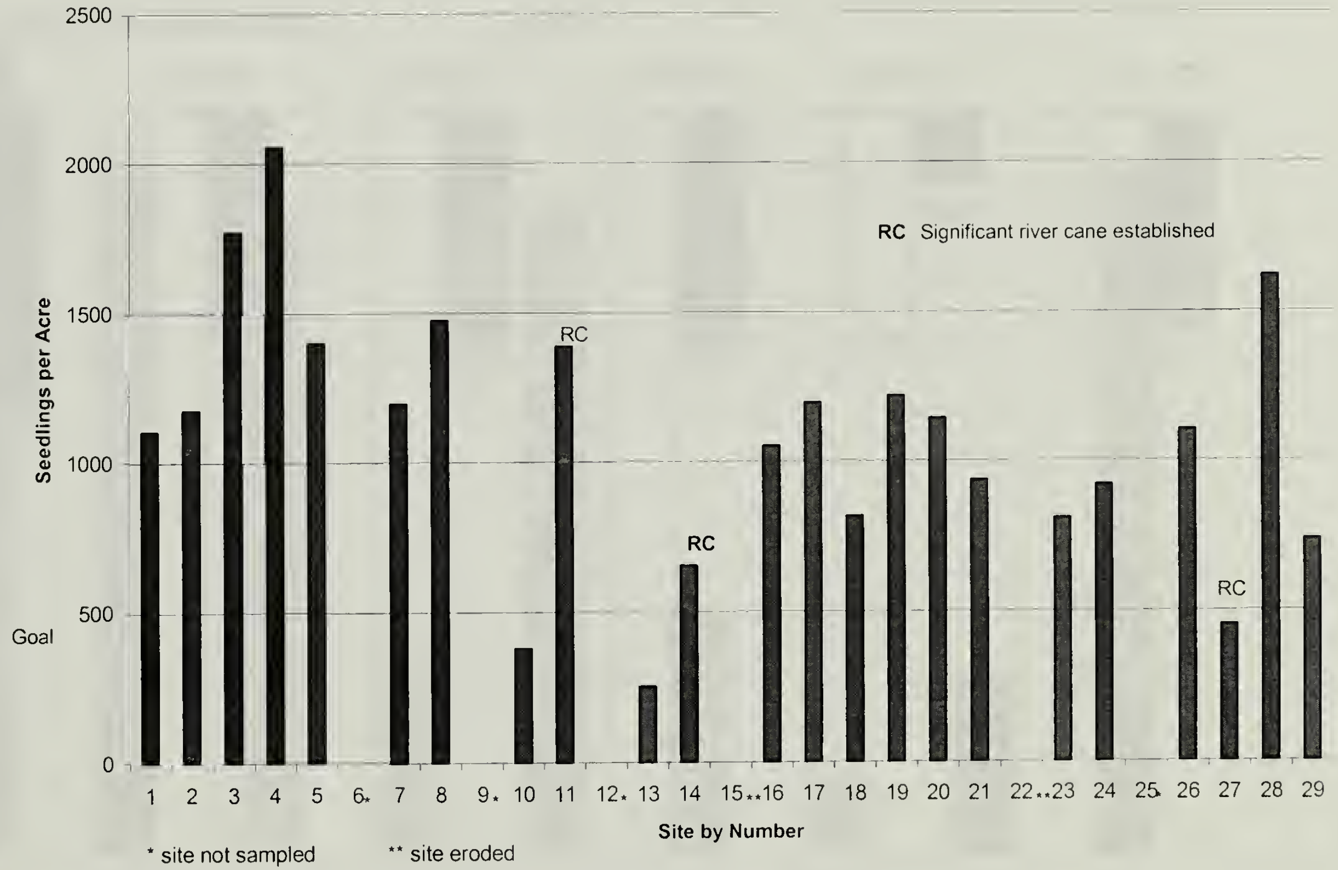


Figure 23: Seedlings Per Acre of Planted and Volunteer Species.

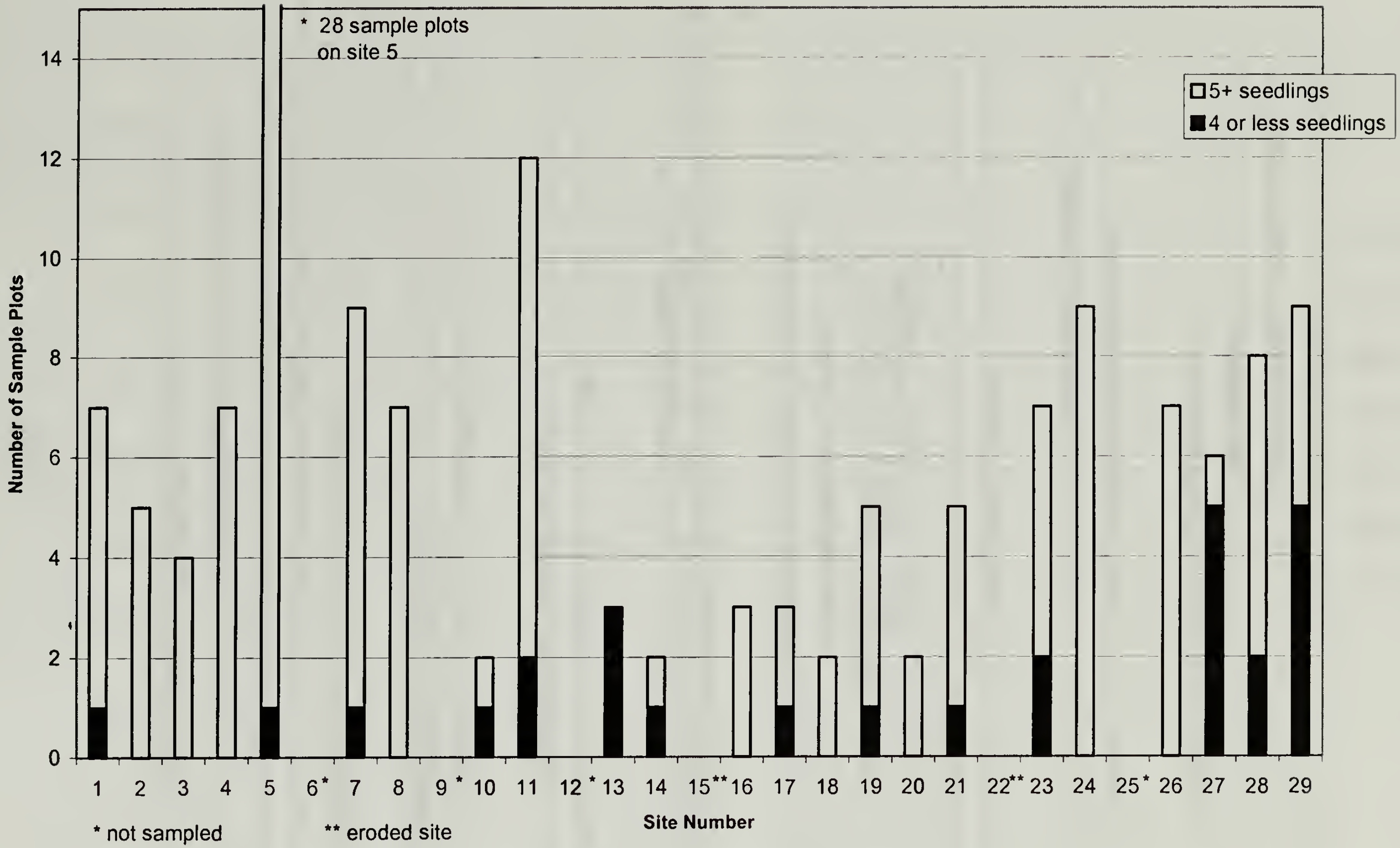


Figure 24: Plots Above and Below the Goal of Five Seedlings/Plot.

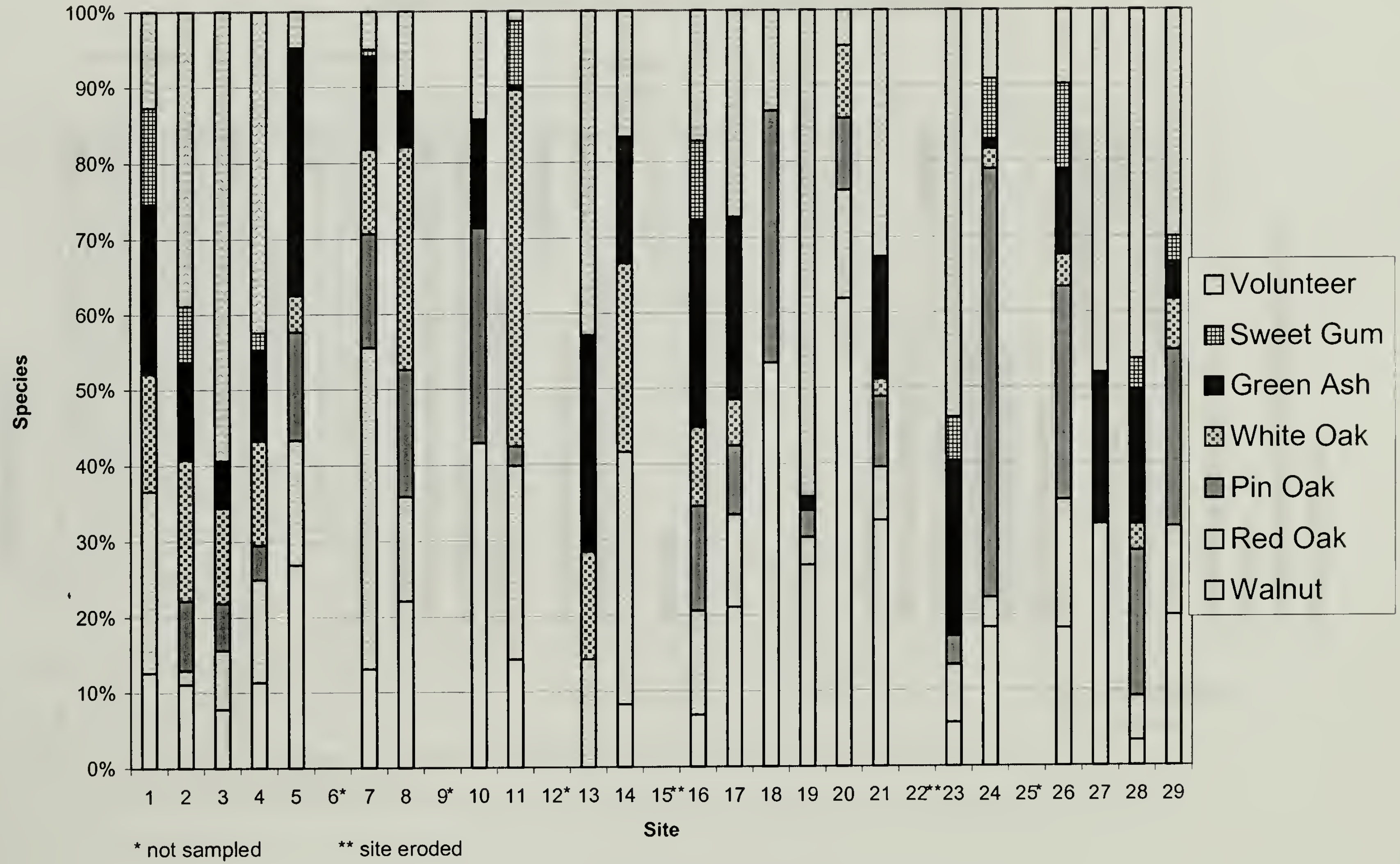


Figure 25: Relative Abundance of Each Species at each Buffer Site.

Section D

Alternative Strategies for River Management

This section provides a brief overview of some streambank stabilization techniques other than cedar revetments that have been implemented on the Buffalo River and tributaries. Techniques discussed include whole willow transplanting, gravel bar spawning through the use of willow transplanting in targeted hydrologic reaches, and installation of rock vanes. These techniques were developed to augment cedar revetments or to use at those sites where completion of the Site Assessments Questionnaire indicated cedar revetments were not practical.

Technique 1: Whole willow transplanting within the toe of the revetment

Numerous bioengineering projects have been installed that utilize some form of willow (*salix sp*) transplanting. Most often, willow staking (cut segments of trunks or branches driven into a back-sloped bank either alone or in combination with other bioengineering practices, revetments, or hard-structures) or willow fascines (bundles of willow branches laid into trenches dug horizontally along a back-sloped erosion bank and staked down) are the techniques most commonly used. At Buffalo National River we have experimented with both techniques, especially with willow staking,. We have had very little success and have never been able to meet our goals with these approaches. In fact, we are not aware of anyone that has had long-term success with willow staking or fascines in the Arkansas Ozarks. Field observations suggest that the frequent recurrence of spring floods, followed by extreme low stages and dry, hot conditions in the summer are too much for non-rooted willows to withstand.

Because of the flash-flood nature of the Buffalo River and the relatively high velocity of flood-waters, a few revetment sites were experiencing enough scour to substantially diminish the amount of sediment trapped within the revetment. This lack of deposition was associated with physical abrasion of the revetment. At these sites, it became apparent that the revetment was not going to last long enough to allow vegetation derived from seeds deposited within the revetment to stabilize the bank. The need to propagate within channel vegetation to stabilize the toe of the revetment became a prominent issue at these sites. Based on this need, the decision was made to expend additional energy conducting further tests with willow transplanting, and including the transport of the roots.

Most of our construction activities took place during the summer when river levels were usually low and work within the stream channel was more practical. We experimented with two modified approaches to whole willow transplanting: with and without the stems. In other words, at one site (Ferguson's), we transplanted the entire willow plant, at another site, (South Maumee) we transplanted the entire plant and then cropped the willow plants, cutting off the stems above the ground. Our technique was to dig a trench or trenches near the base of the cedar revetment (Photo 30) along the toe of the bank, and then cross the channel and use a backhoe to dig up entire willow plants, or as much as practical, roots and all, and plant them in the trench. In summary, both of these techniques failed almost totally when conducted during the summer growing season.

Our next experimentation phase involved attempting whole willow transplanting one more time, but doing the work in the dormant season. We returned to the Ferguson site in February during a window of low-flow conditions. Approximately 40 individual willow plants were transplanted into a 75 feet long trench. The trench was excavated to a depth below the lowest level of summer flow. The bushy portions of the willow plants were not removed. When spring came, all of the willows leafed out, survived the first summer, and displayed vigorous growth. The willow trench also helped to protect the lower end of the Ferguson revetment and provide hydraulic roughness and encourage a depositional environment (Photo 31).


Photo 38: Trench dug horizontally along toe bank for willow transplanting.


Photo 39: Transplanted willows at the Ferguson revetment.

Technique 2: Gravel bar spawning through whole willow transplanting

In our work with private landowners over the years we have encountered a very common theme. Landowners are convinced that willows growing within the river channel are the cause of much of the flow diversion that shifts high velocity flood waters against stream banks and initiates and procrastinates bank erosion. Recent work by McKinney et al. (1996), while pointing out that the situation is more complex than often expressed by landowners, generally supports their observations that willow (and other woods species) incursion within the channel is one of the major elements promoting meander processes.

Analysis of disturbance zone dynamics as observed from aerial photography taken over many years, field observations, and literature reviews, lead us to hypothesize that flow directions within channels could be manipulated through whole willow transplanting into specific hydrologic environments. In essence, whole willow transplanting techniques are used to encourage the formation of point bars above eroding stream banks. The process is outlined in Figure 26 and in Photos 32 and 33.

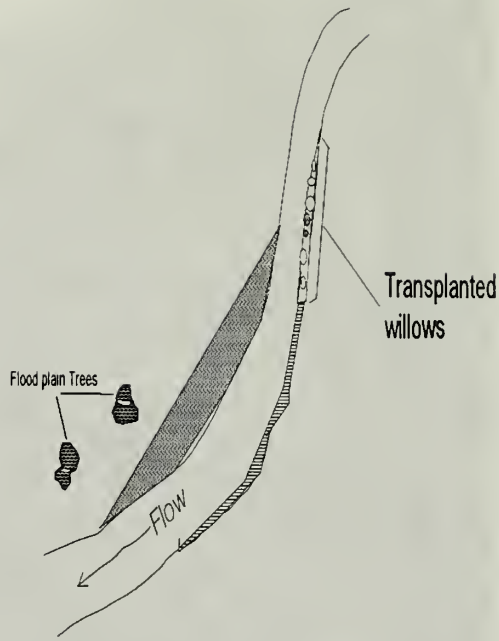
The use of willows to spawn gravel bars has the potential to greatly augment stream restoration with very little impact to natural processes. Gravel bar spawning is also relatively easy to accomplish, very cost effective, and can be done in small increments over time thus drawing very little attention to the activity. Several field trips and workshops have been conducted at the sites where we have used gravel bar spawning techniques and no one, not even fluvial geomorphologists with years of experience working with Ozark streams, noticed our activities. Other advantages include a quicker response time to potential problem areas (in fact, problem areas can even be anticipated and reacted to before streambank erosion becomes severe), less compliance as there is no net change (either dredging or filling) below the ordinary high water mark, little if any chance of disturbing archeological sites within the active channel. There is also little potential for other than minor, short-term impacts to aquatic communities and habitats.

One word of caution is that this technique is completely new and continued monitoring will be required to determine if the technique holds-up over time, and especially through large floods. A ready source of willows is also a requirement.

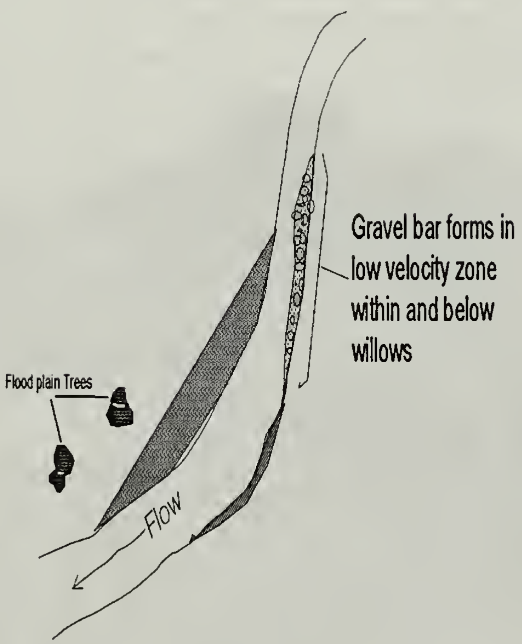
Photo 40: View looking upstream of willows transplanted to spawn gravel bars.


Photo 41: View looking downstream of willows transplanted to spawn gravel bars.

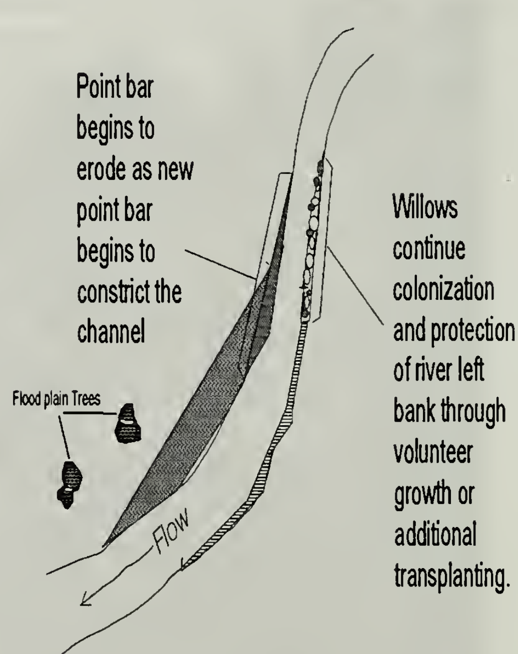
Sketch 1: Pre-action setting.



Sketch 2: Location of transplanted willows.



Sketch 3: Point bar "spawning".



Sketch 4: Shifting direction of erosion.

Figure 26: Conceptual sketches of gravel bar spawning.

Technique 3: Rock Vanes

As is self evident based on this review of cedar revetments, not all eroding banks can be stabilized with bioengineering. In selected areas, such as canoe launch accesses or private properties outside the national river boundary, we have determined that hard structures were needed to address resource concerns associated with streambank or launch erosion. For example, at canoe launch points natural riparian vegetation has been removed or destroyed by human disturbance (trampling). In some areas this removal of vegetative stability has resulted in unnatural erosion rates. In addition, park maintenance activities at these sites included the dumping of fill within the channel at the launch. This fill was subsequently removed by the next high water event (in some cases with a net loss of bank material as well) and the process would have to be repeated. Over the years, a significant amount of material was added to the Buffalo River, possibly degrading downstream habitat. The Corps of Engineers has notified the park that dumping of fill below the ordinary high water mark is a violation of the Clean Water Act and a 404 permit could not be issued for such activities.

At two launch sites on the Buffalo River, it was determined after thorough review that additional stabilization was needed. After nearly ten years of studying this issue, the staff and management at Buffalo National River decided that rock vanes provided the least impacting tool to accomplish stabilization in these reaches where full restoration was not possible because the anthropogenic disturbance could not be effectively removed. Similarly, we constructed two rock vanes on private property within the Buffalo River watershed at Cave Creek where bioengineering alone was determined impractical. The Cave Creek project was a cooperative demonstration project between NPS, Natural Resources Conservation Service, Newton County Conservation District, and the landowner.

Rock vanes are sometimes lumped in with bend-away weirs, but they have more specific design criteria as follows: they are constructed using large boulders and dry-stack masonry techniques; they key into the bank at the bank-full elevation; their long-axis is oriented 30 degrees from the upstream bank; they have a one to ten slope from bank-full into the channel; the footing is placed at a depth at least two feet below the elevation of the thalweg, the spacing between structures is two (small radius of curvature) to two and one-half times (straighter reach) the effective coverage of any one vane. Rock vanes shift the location of the thalweg to the end point of the vane. The upstream angle also orients high velocity flood waters that over-top the vane toward the center of the stream. They dissipate stream energy so that downstream reaches experience a slow return to natural conditions in the near-bank region. Rock vanes also promote deposition of bedload in the vicinity where the structures are keyed into the bank and just below the structure.

While rock vanes were not the focus of this assessment, we felt it was important to present an alternative to rip-rap or gabions that will work where bioengineering methods are not applicable. The vanes we have constructed have been in the stream less than two years, but our initial results are very positive and we have not had to dump any fill on the canoe launches since we installed the vanes. Photos and a brief discussion of the rock vanes installed on the upper Buffalo River at the Steel Creek launch are shown in photo series 42 through 46.

Photo 42: Footer for rock vane looking from midstream, note 30 degree angle from bank.

Photo 43: View from upstream of completed vane before backfilling, note 1:10 slope from bankfull into the channel.

Photo 44: View from upstream of completed vanes at Steele Creek launch.

Photo 45: View of the Steel Creek rock vanes from Bee Bluff – Dec., 2001; This view shows the major operational factors of the vanes. These are: 1) shifting of the thalweg away from the cut-bank, 2) upstream orientation of the vanes which allows water over-topping the vanes to be directed back toward the channel, 3) tie-in of vanes with the bank-full elevation, and 4) energy dissipation (white water) as the water passes over the vanes, which protects the downstream riparian corridor and bank.

Photo 46: Rock vanes on Buffalo River near Steel Creek after flood exceeding bankfull flow. View is up stream, note a) shifted thalweg b) pour-off directed toward thalweg, c) near zero velocity and turbulence near bank, and deposition of fine sediment between and below the vanes.

Section E

In-Stream Biological Assessment

Introduction to Section E

In 1994 Buffalo National River initiated a stream-bank stabilization project for the purpose of stabilizing eroding stream-banks and restoring riparian areas disturbed by agricultural clearing prior to the establishment of the National River. Fourteen streambank restoration sites totaling 5,225 feet in length were targeted for mitigation using cedar revetments and other bioengineering techniques. Work was completed during the summers of 1994, 95, and 96. This section focuses upon the macroinvertebrate communities adjacent to the stabilization sites by conducting physcial habitat and rapid biological assessments above and below the stabilization sites.

Methods

Bank stabilization was attempted at fourteen sites with varied results. Of the fourteen sites, four were selected to represent the suite of conditions now found at reveted sites. Selected sites were meant to represent effective, moderately effective, and no-effect conditions. Effective stabilization sites selected were Bakers Ford (BF1 and BF2) and Sheldon Branch Field (SF1 and SF2). Moderately effective sites were represented by the Angle Field site (AF1 and AF2), and the no effect sites were represented by the Calf Creek site (CC1 and CC2) {see main assessment report for photo-documentation}. The designation of the numeric portion of the site code indicates the macroinvertebrate community habitat sampled upstream of the stabilization site (i.e. CC**1**) and downstream of the stabilization site (i.e. CC**2**).

Physical habitat characterization protocols used in this assessment were taken directly from the latest EPA recommendations (Barbour et. al., 1999). The habitat assessment form for high gradient streams was used and scores were generated based upon the consensus of the survey team. Each team member generated visual estimates and the average visual estimate was recorded. The inorganic substrate components were designated after the riffle habitat was completely observed. Habitat scores were a compilation of observations based upon the following categories: epifaunal substrate/available cover, embeddedness, velocity/depth regime, sediment deposition, channel flow status, channel alteration, frequency of riffle habitats (not scored), bank stability for each bank, vegetation protection for each bank, and riparian zone width. Top ranking score possible was 180 and the lowest was zero. Surface velocities were taken at several locations from within the riffle habitat and an average was recorded. Stream depth was also taken from several locations and an average was recorded. Canopy coverage was measured using a hand-held densiometer, and the measurement was taken from the center of the habitat. Length and width measurements were taken at midpoint of both the latitude and longitudinal aspect of the riffle habitat.

Macroinvertebrate community assessments also followed recommendations from the recent EPA protocols (Barbour et. al., 1999). A single habitat approach was used to represent the riffle community by sampling eight *kick* locations (approximately 2 square meters total). The eight kick samples were composited and then homogenized. Once sufficiently mixed, one 100 cubic centimeter subsample was removed and placed into a white picking pan. Out of this subsample, 100 benthic organisms were removed and placed into a container of 70% alcohol with interior and exterior labels. If 100 organisms were not taken with the first subsample, then the composite was rehomogenized and another 100 c.c. sub-sample was taken. Preserved macroinvertebrates were then transported back to the laboratory for processing.

Preserved organisms, once ready for identification, were placed into a 150-micrometer sieve and washed free of preservative. Macroinvertebrates were sorted and identified to the lowest taxonomic level practical, typical at the genus level. Three major taxonomic keys were used in identifying the macroinvertebrates (Merritt and Cummins 1996, Wiggins 1998, and Stewart and Stark 1993). Reference organisms, if not already cataloged by previous macroinvertebrate studies, were placed into the BUFF working collection, and voucher validation of delineation was deemed unnecessary at the genus level of identification.

Results

The majority of the inorganic substrate observed within the riffle habitats were cobble with a subcomponent of gravel; however, a large range in proportions was observed among sites (Table 2). Cobble percentages ranged from 80% at Baker Ford Upper (BF1) to 5% at Calf Creek Upper (CC1). The highest observed gravel component was at Calf Creek Upper (CC1) which was 95% of the substrate. Calf Creek was the only tributary system assessed, all other sites were located on the main-stem of the Buffalo River. Highest in sediment (silt/mud substrate) coverage was Calf Creek Lower (CC2), which had 65% of the benthic substrate inundated by fine silt and colloidal clay. The Calf Creek sites were also highest in organic detritus, with CC1 at 25% and CC2 at 30%. Comparisons of inorganic substrate types among the sites exhibited an even distribution of substrate types with the exception of Baker Ford Lower and both Calf Creek sites (Figure 27). Baker Ford Lower had a large component of bedrock. Calf Creek Upper was gravel dominated and Calf Creek Lower was dominated by mud/silt substrates. All other sites were similar with cobble/gravel aggregates being the most dominant.

Table 2. Percentages of observed inorganic substrate from each riffle assessment.

Sites	Bedrock(%)	Boulder(%)	Cobble(%)	Gravel(%)	Sand(%)	Mud(%)	Detritus(%)
AF1		5	60	35			15
AF2		5	60	35			
SF1		5	75	20			2
SF2		5	75	20			1
BF1		10	80	10			7
BF2	40	5	30	20	5		2
CC1			5	95			25
CC2			15	20		65	30

Table 3. Physical measurements and habitat characterization scores for riffle habitats.

Sites	Length(ft)	Width(ft)	Area(ft3)	Depth(in.)	Velocity(ft/s)	Canopy(%)	Habscore
AF1	60	12	720	4	0.68	15	127
AF2	120	15	1800	4	0.7	10	135
SF1	140	16	2240	9	1.6	0	142
SF2	175	18	3150	7	3.33	0	120
BF1	148	29	4292	24	1.86	64	136
BF2	171	69	11799	14	1.88	0	155
CC1	196	23	4508	6	0.51	0	130
CC2	70	20	1400	4	1.32	0	71

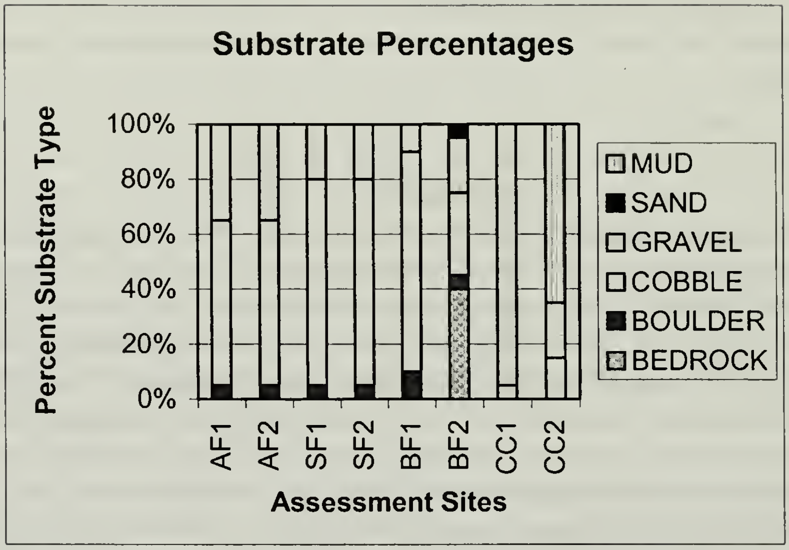


Figure 27. Inorganic substrate percentages at the macroinvertebrate assessment sites.

The site below Baker Ford (BF2) had the highest habitat characterization score, which was 155 (Figure 28, Table 3). The average habitat score for all sites was 127. Calf Creek lower (CC2) had the lowest score, 71. The habitat characterization scores were higher at the effective sites, and lower a the no-effect site.

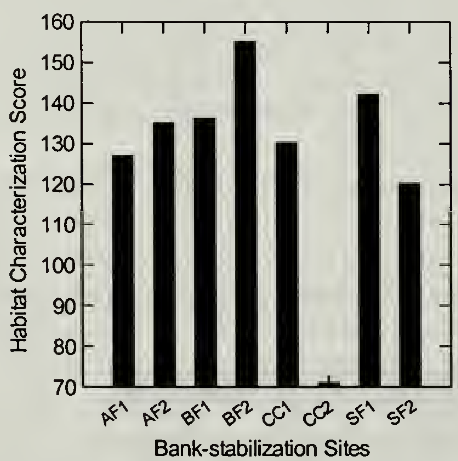


Figure 28. Habitat Characterization scores for the bank-stabilization sites.

Taxa Richness is the number of distinct taxa within a community or represented sample which represents the community's ability to support numerous niches (Barbour et. al., 1999). The maximum taxa richness observed was at Angle Field, both above and below, 16 and 15 respectively. Taxa richness was lowest at Calf Creek Lower (CC2) with 9 species represented. The average taxa richness value for all sites was 13 taxa (Figure 29). No potential relationships were found between habitat characterization scores, depth, and area with taxa richness.

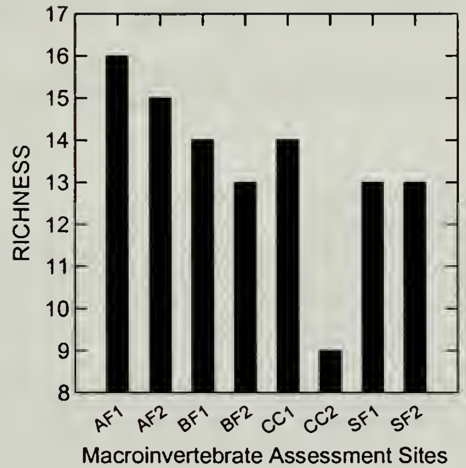


Figure 29. Taxa richness representing macroinvertebrate communities at bank-stablization sites.

Ephemeroptera/Plecoptera/Trichoptera (EPT) taxa (generally considered pollution intolerant, Barbour et. al., 1999), Dipterans, and Oligochaetes were computed as the percentage represented in the riffle sample. The EPT taxa group ranged between 85%, recorded from Calf Creek Upper (CC1), to 50%, recorded from Calf Creek Lower (CC2; Figure 30). Percent Diptera was highest at 47% from Calf Creek Lower and lowest at 2% from Baker Ford Upper (BF1). EPT and Diptera percentages were both at or near the 50% of the sample at Calf Creek Lower, a split within the community between pollution tolerant and intolerant organisms (Figure 30). Oligochaetes were only present at four sites and were low in percent total of sample. There were no Oligochaetes found at the Calf Creek Lower site.

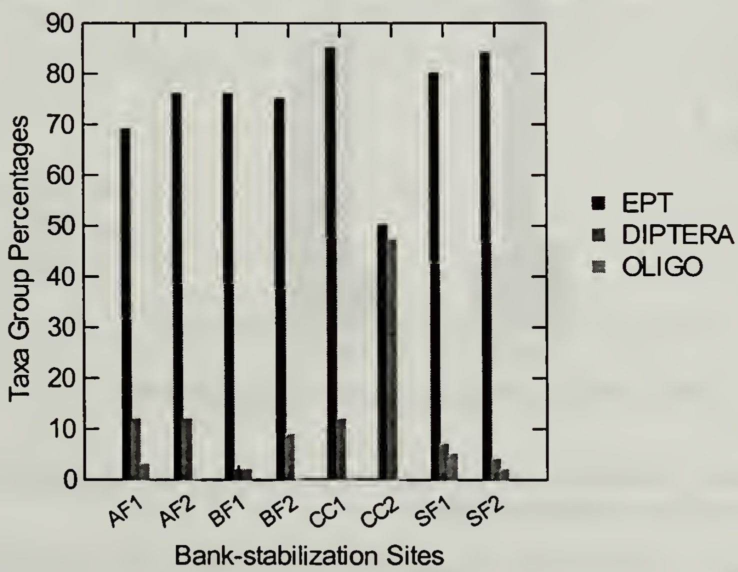


Figure 30. Percent EPT, Diptera, and Oligochaets of samples taken from bank-stabilization sites.

Potential relationships were examined between EPT, Diptera, Oligochaetes, habitat characterization scores, and percentage of substrate type using a Spearman's rank correlation, which is a non-parameter test for covariates. The only relationships found were with macroinvertebrate taxa group Diptera. Percent Diptera was related to increases in
% gravel (0.641, p-value <0.05) and detritus (0.764, p-value <0.05), and decreases in % cobble (-0.827, p-value ,0.05).

Calf Creek, as seen in prior tables and figures, had the greatest difference in macroinvertebrate communities above and below a bank stabilization site. Both taxa richness and % EPT were much lower downstream of the stabilization site, and % Diptera was much higher (Figure 31). No other site within the highly effective or moderately effective categories exhibited as large a difference between the macroinvertebrate taxa groups. At the Angle Field and the Sheldon Branch Field sites, increases in % EPT were observed at or below the rehabilitated banks (Figure 31).

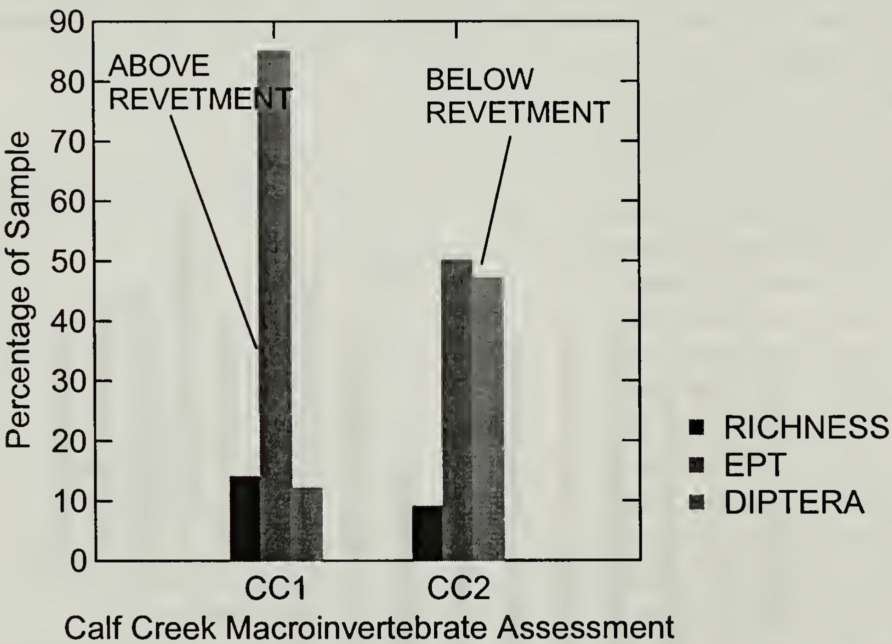


Figure 31. Differences between the above and below macroinvertebrate community taxa groups at the Calf Creek bank-stabilization site.

Percent difference (A-B/A+B*100) was calculated to examine the magnitude of difference between the upstream and downstream communities at each of the attempted bank-stabilization sites for the community metrics of taxa richness, %EPT, and %Diptera. For taxa richness, Baker's Ford, Sheldon Branch Field, and Angle Field were slightly different in the upstream and downstream sites' taxa richness (3.7, 0.0, and 3.2%, respectively). Calf Creek had the highest percent difference between sites, 21.7% difference. Differences between above and below for % EPT followed a similar pattern as with taxa richness: Baker's Ford (0.6%), Sheldon Branch Field (2.4%), Angle Field (3.2%), and Calf Creek (25.9%). Percent differences between above and below based upon % Diptera did not follow the previous patterns. Baker's Ford (63.6%) was the highest followed by Calf Creek (59.3%), Sheldon Branch Field (27.3%), and Angle Field (0.0%).

Discussion and Conclusion

Bank-stabilization efforts as measured by the four macroinvertebrate community assessments should be considered as beneficial to the aquatic resources of the tributary and river system. The sites representing effective and moderately effective stabilization efforts exhibited little differences in the macroinvertebrate communities between the upper and lower habitats suggesting that bank-stabilization efforts have been a success even at the moderately effective sites. Relatively high habitat characterization scores were observed at these sites indicating that the bank stabilization efforts were effective and benefits were long-term. However, the failed Calf Creek stabilization site had major differences in the macroinvertebrate communities above and below the stabilization zone, and data suggests change in the taxa composition was influenced by the large differences in the substrate composition, both inorganic and organic. Sites of catastrophic failure such as Calf Creek were rare among the 14 total stabilization sites. Overall efforts at bank stabilization were considered successful as indicated by small percent differences in the macroinvertebrate communities above and below the stabilization sites.

As seen in the results of this supplemental investigation, any efforts made at bank stabilization are directly beneficial to the aquatic resources of the Buffalo National River and it's tributary systems. Increases in habitat quality through bank-stabilization efforts can be directly related to increases in macroinvertebrate community health and protection of aquatic resources

References

Barbour, M. T., J. Gerritsen, B. D. Snyder, J. B. Stribling, 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates, and Fish. Second Edition. EPA 841-B-99-002.

Fantz, J., D. Lobb, M. Matheney, B. Todd, W. Turner, and R. Wehnes, 1993. A status report of stream projects installed in Missouri from 1987 to 1992. Missouri Dept. of Conservation, Fisheries Division.

Gough S., 1990, Stream fish habitat response to restoration using tree revetments. Proc. of Symposium on Restoration of Midwestern Streams, 52nd Midwest Fish and Wildlife Conference. North-Central Division of the American Fisheries Society.

Jacobson, R.B., A.J. Miller, and S. Gough, 1990. Effects of land use, climate, and large floods on gravel aggradation, instability, and fisheries in Missouri Ozark streams [abstract]: EOS, v.71, p.1322.

Jocobson, R.B., and Bobbitt, G., Gravel sediment routing from widespread, low-intensity landscape disturbance, Current River Basin, Missouri: *in* Earth Surface Processes and Landforms, v. 24, pp. 897 – 917.

Jacobson, R.B., Pugh, A.L., Riparian Vegetation Controls on the Spatial Pattern of Stream Channel Instability, Little Piney Creek, Missouri, U.S.G.S., Water Supply Paper 2494, 33pp

Jacobson, R.B., 1995, Spatial controls on patterns of land-use induced stream disturbance at the drainage-basin scale – An example from gravel-bed streams of the Ozark Plateaus, Missouri: in Costa, J.E., Miller, A.J. Potter, K.W., and Wilcock, P.R., eds. , American Geophysical Union, Geophysical Monograph 89, The Wolman Volume, p.219-239.

Leopold, L., M. Wolman, and J. Miller, 1964. Fluvial processes in geomorphology. W.H. Freeman and Co.

Merritt, R. W., and K. W. Cummins, 1996. *An Introduction to the Aquatic Insects of North America, Third Edition.* Kendall/Hunt Publishing Company, Iowa.

Mckenney, R., Jacobson, R.B., 1996, Erosion and Deposition at the Riffle-Pool Scale in Gravel-Bed Streams, Ozark Platesus, Missouri and Arkansas, 1990-1995, U.S.G.S., Open File Report 96-655A, Rolla, Missouri, 171 pp.

McKinney, R., Jacobson, R.B., and Wertheimer, R.C., 1995, Woody vegetation and channel morphogenesis in low-gradient, gravel-bed streams in the Ozark Plateaus, Missouri and Arkansas: Geomorphology, v. 13, pp. 175 – 198

Missouri Department of Conservation (MDC), 1986, Tree revetments for streambank stabilization: MDC, Jefferson City, MO.

National Park Service, 1977, Master plan: Buffalo National River, Harrison, AR.

National Park Service, 1985, Boxley Valley, land use plan/cultural landscape report: Buffalo National River,Harrison, AR.

National Park Service, 1992, Resource Management Plan: Buffalo National River, Harrison, AR.

Rabenni, C.F., R.B. Jacobson, 1993, The importance of fluvial hydraulics to fish-habitat restoration in low-gradient alluvial streams: Freshwater Biology, v. 29, 211-220.

Rosgen, D.L., 1994, A Classification of natural rivers: Wildland Hydrology, 1 stevens Lake Road, Pagosa Springs, CO

Stephenson, T., and D. Mott, 1992, GIS analysis determines erosion potential at Buffalo National River basin: Park Science, Fall 1992, Corvallis, OR.

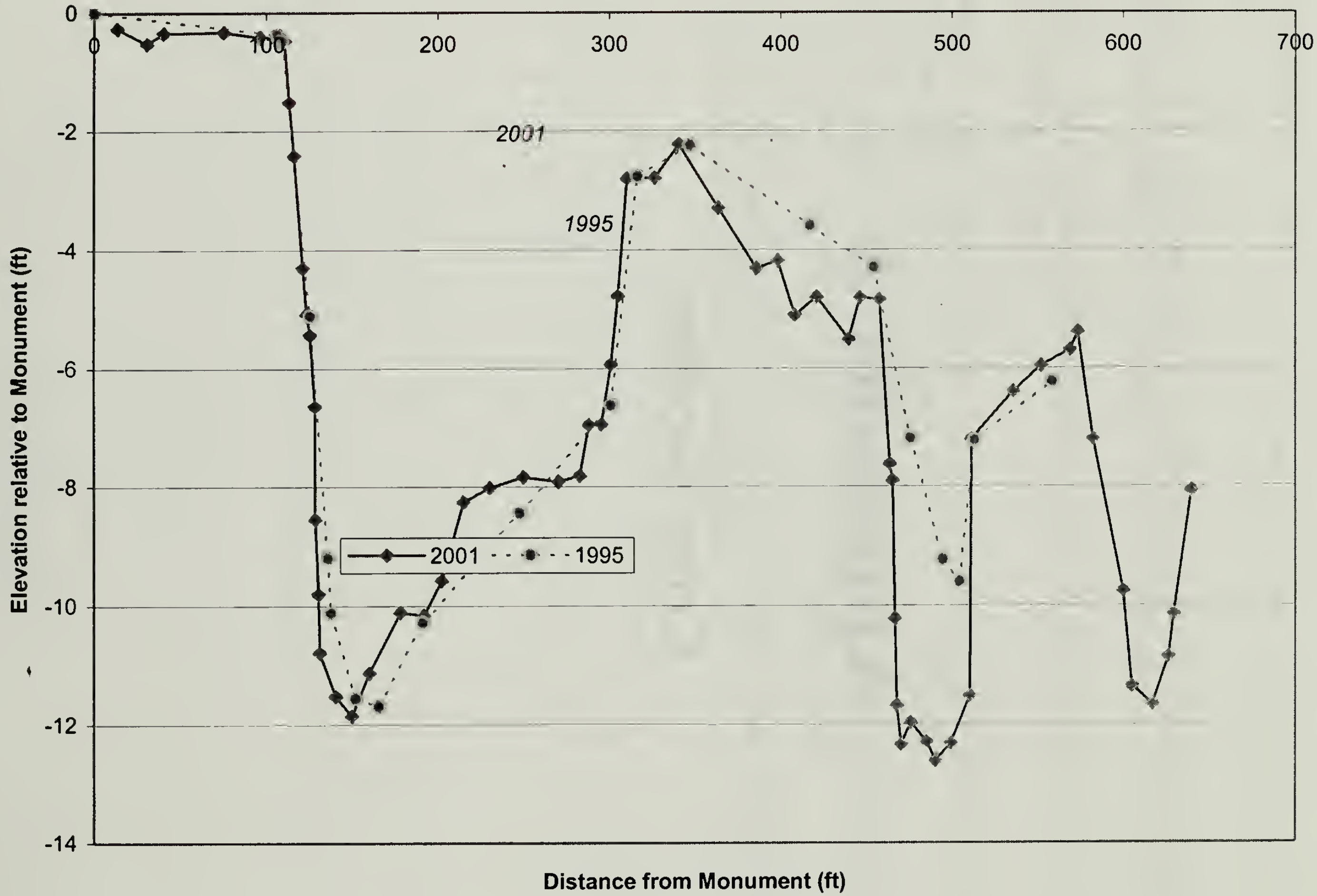
Stewart, K. W., and B. P. Stark, 1993. *Nymphs of North American Stonefly Genera (Plecoptera).* University of North Texas Press, Denton, Texas.

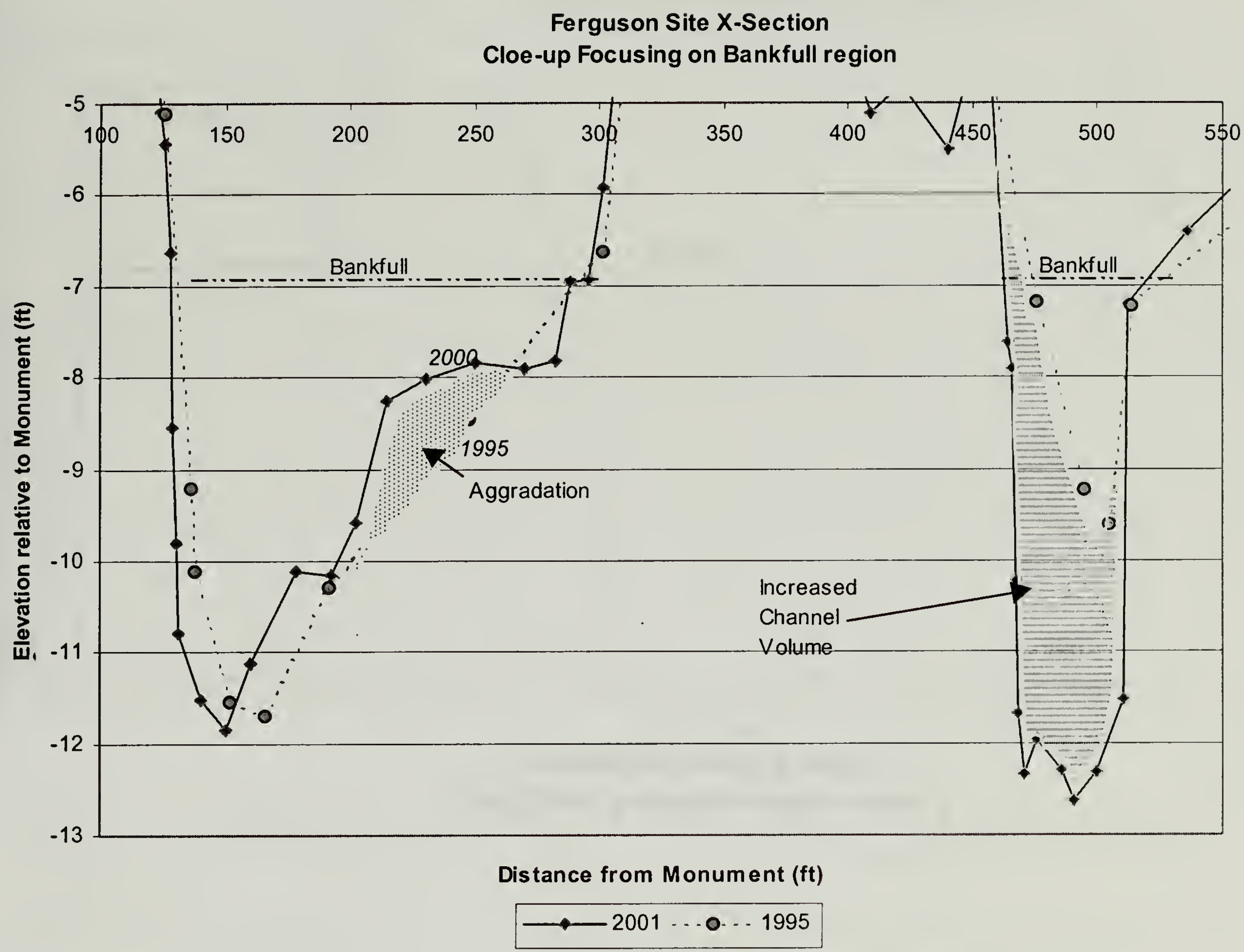
Wiggins, G. B., 1998. *Larvae of the North American Caddisfly Genera (Trichoptera). Second Edition.* University of Toronto Press.

Appendix A

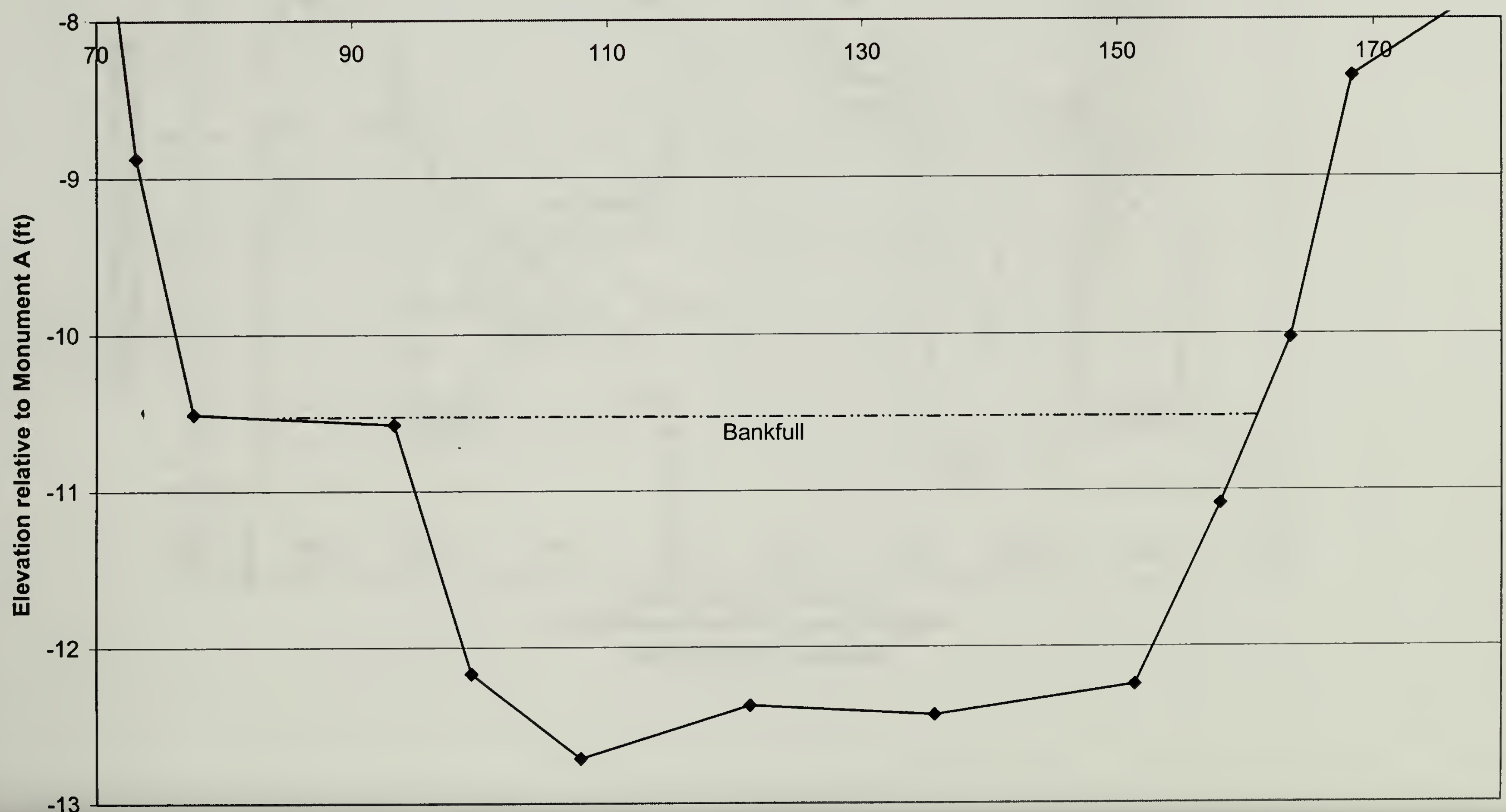
Cross Sections

Ferguson Site X-Section

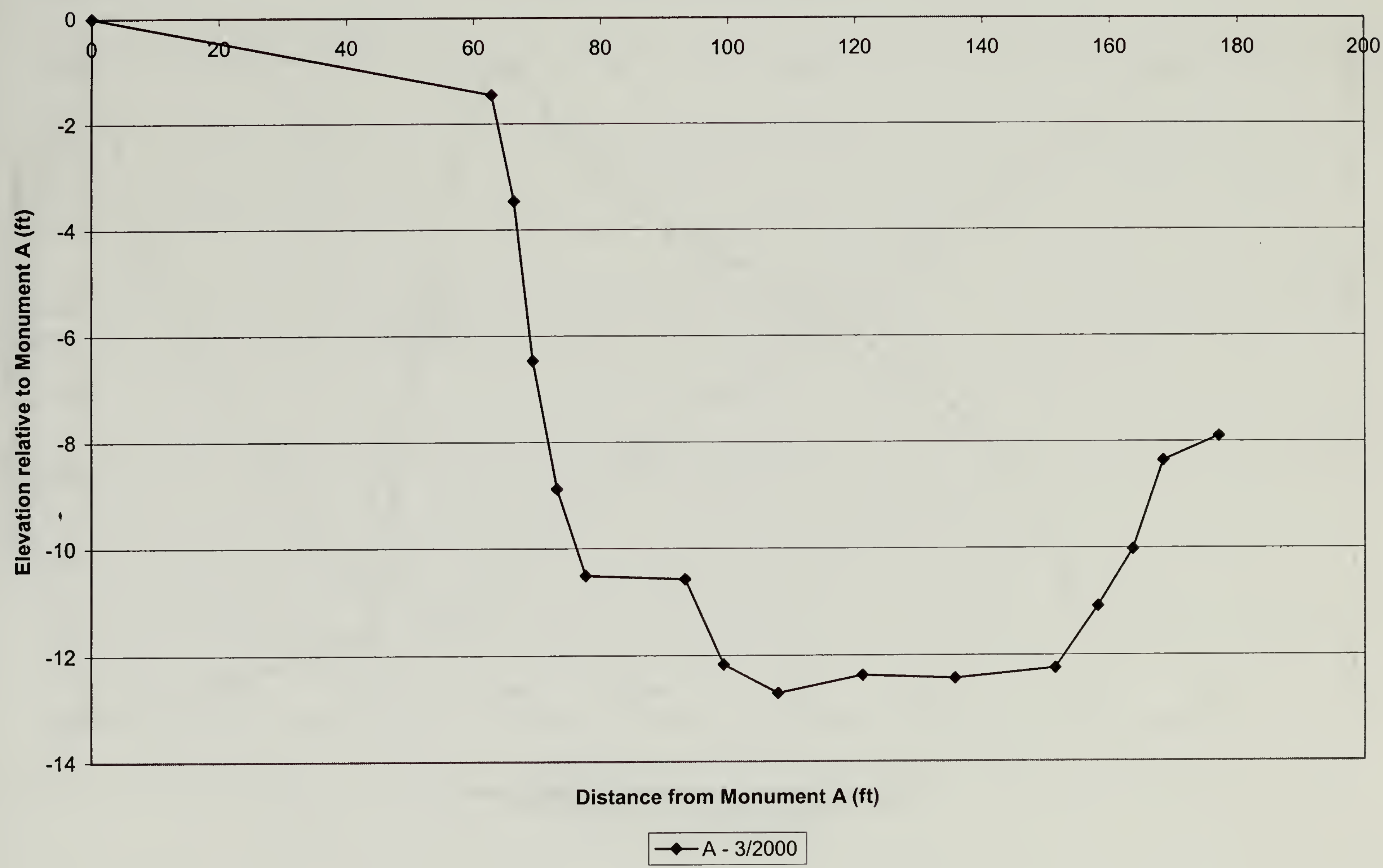


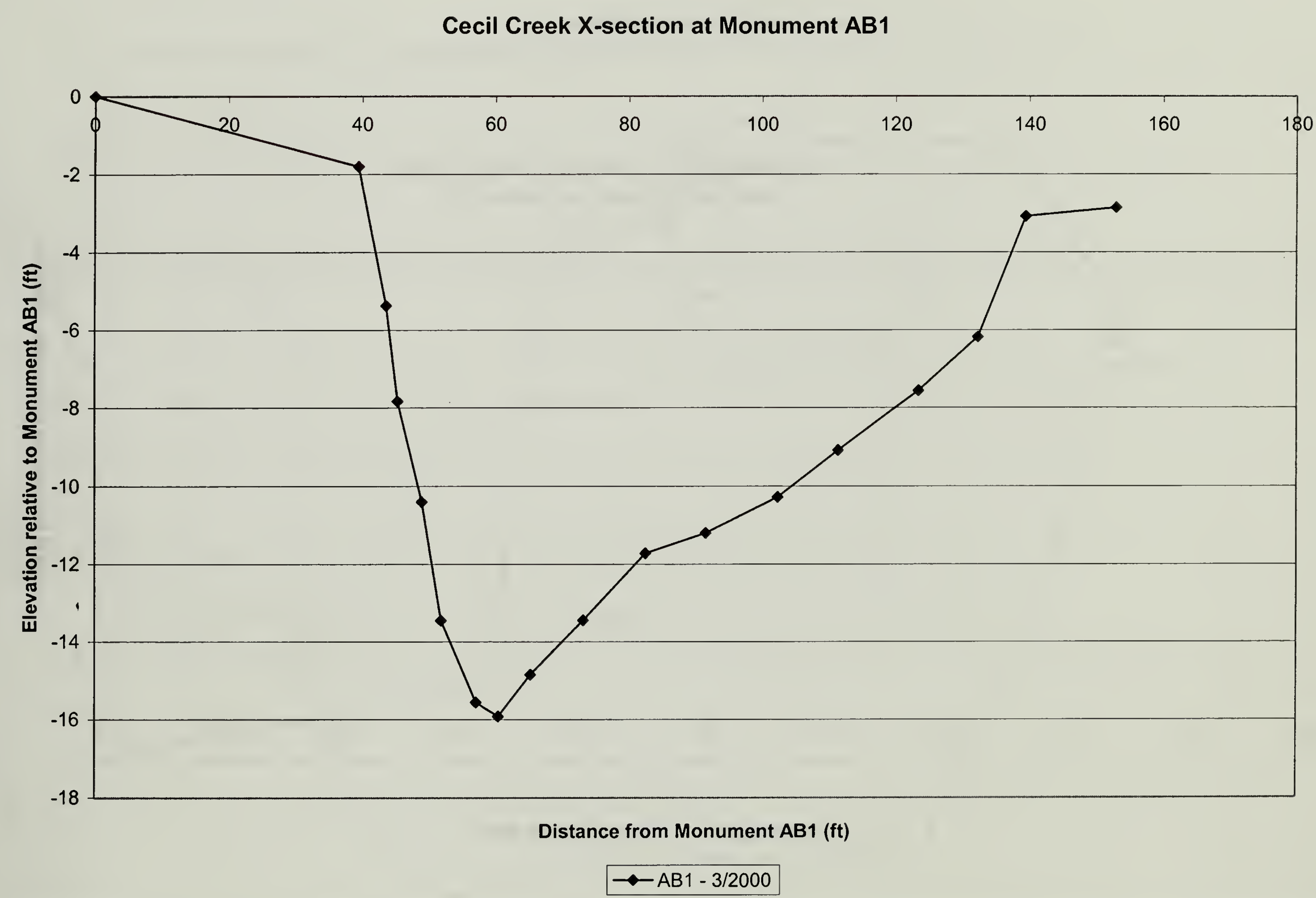

Ferguson Site X-Section
Cloe-up Focusing on Bankfull region
-5
-6
-7
-8
-9
-10
-11
-12
-13
100
150
200
250
300
350
400
450
500
550
Bankfull
Bankfull
2000
1995
Aggradation
Increased
Channel
Volume
Elevation relative to Monument (ft)
Distance from Monument (ft)
2001
1995

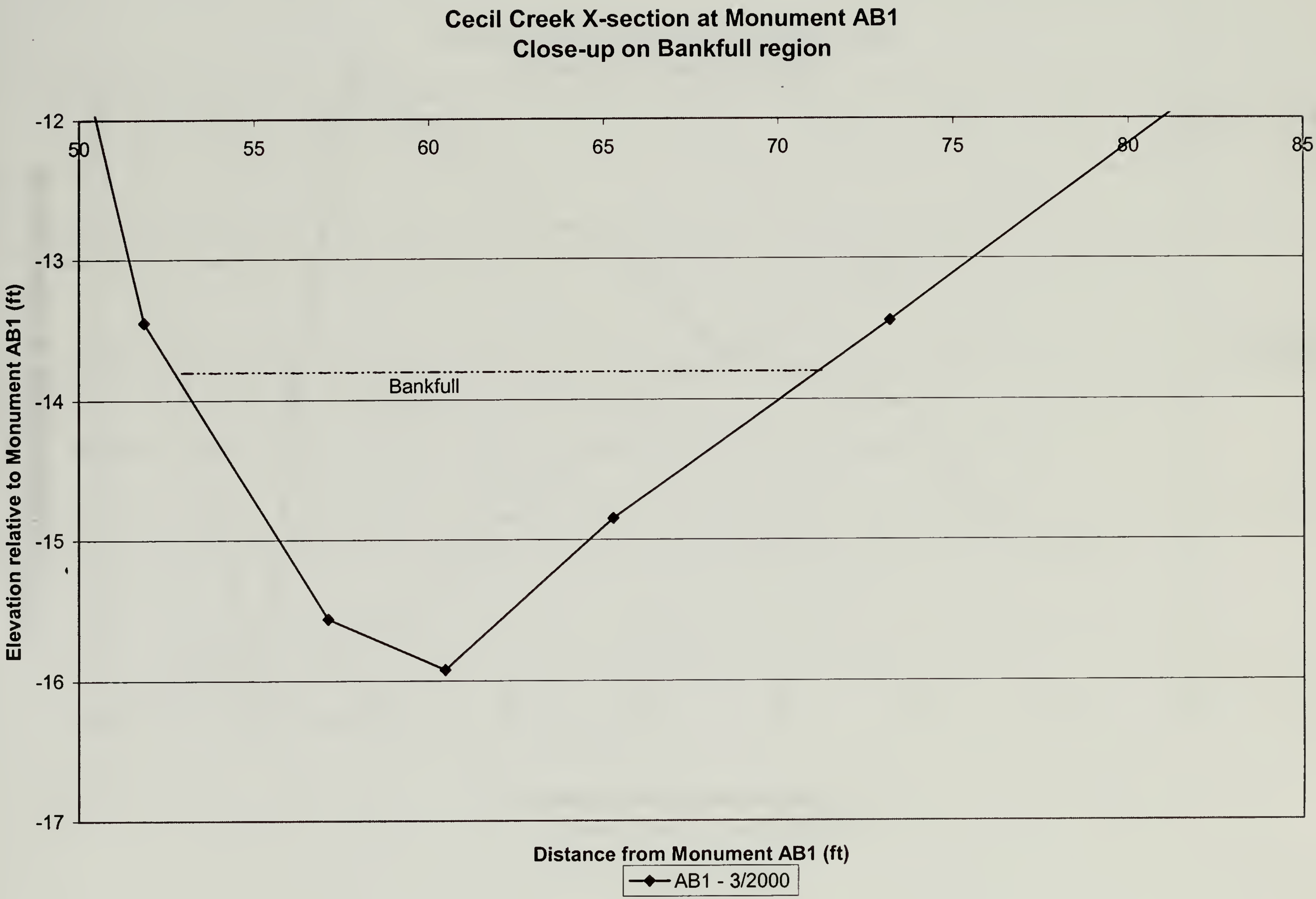
Cecil Creek X-section at Monument A
Focusing on bankfull region

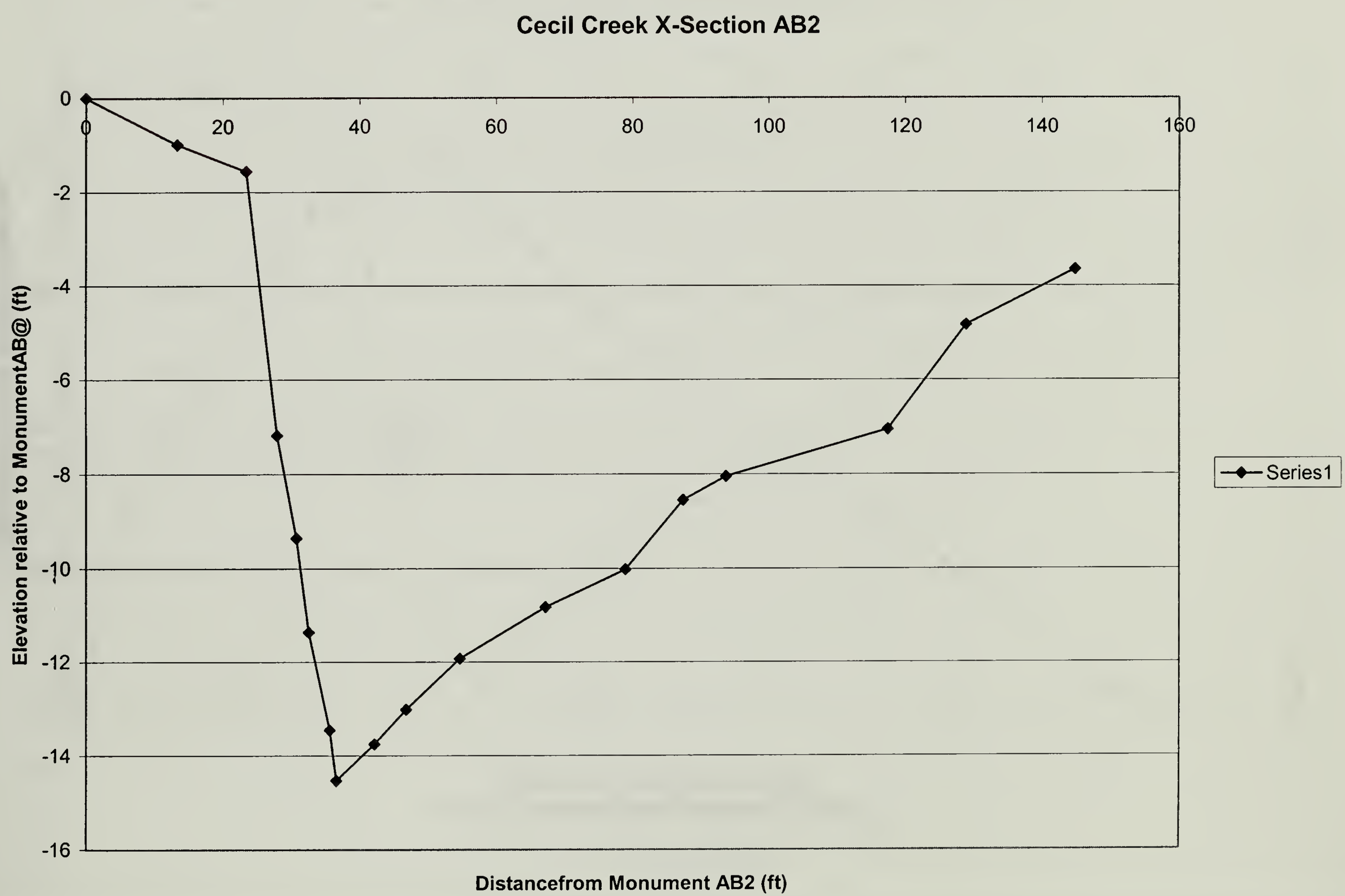


Cecil Creek X-section at Monument A

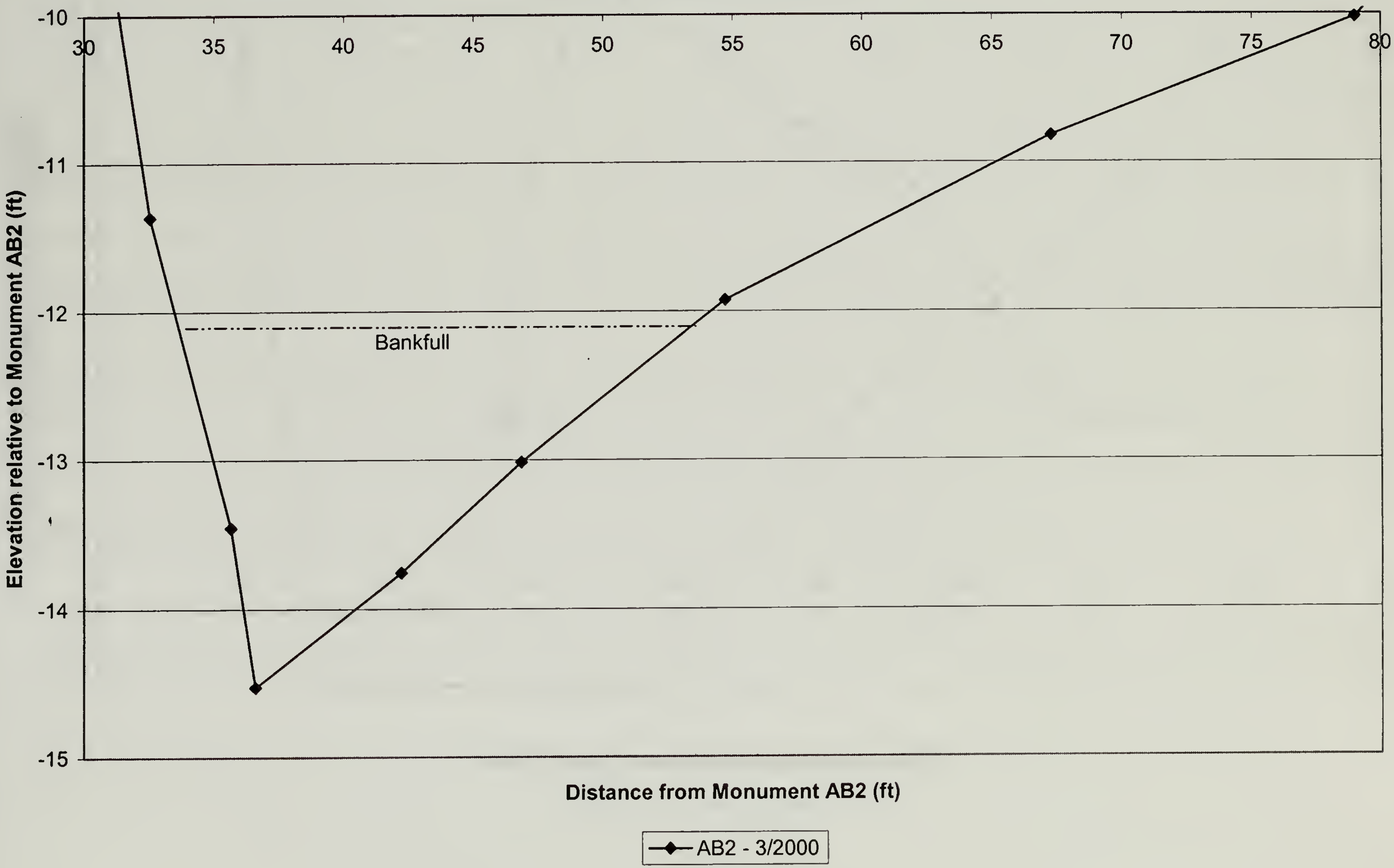


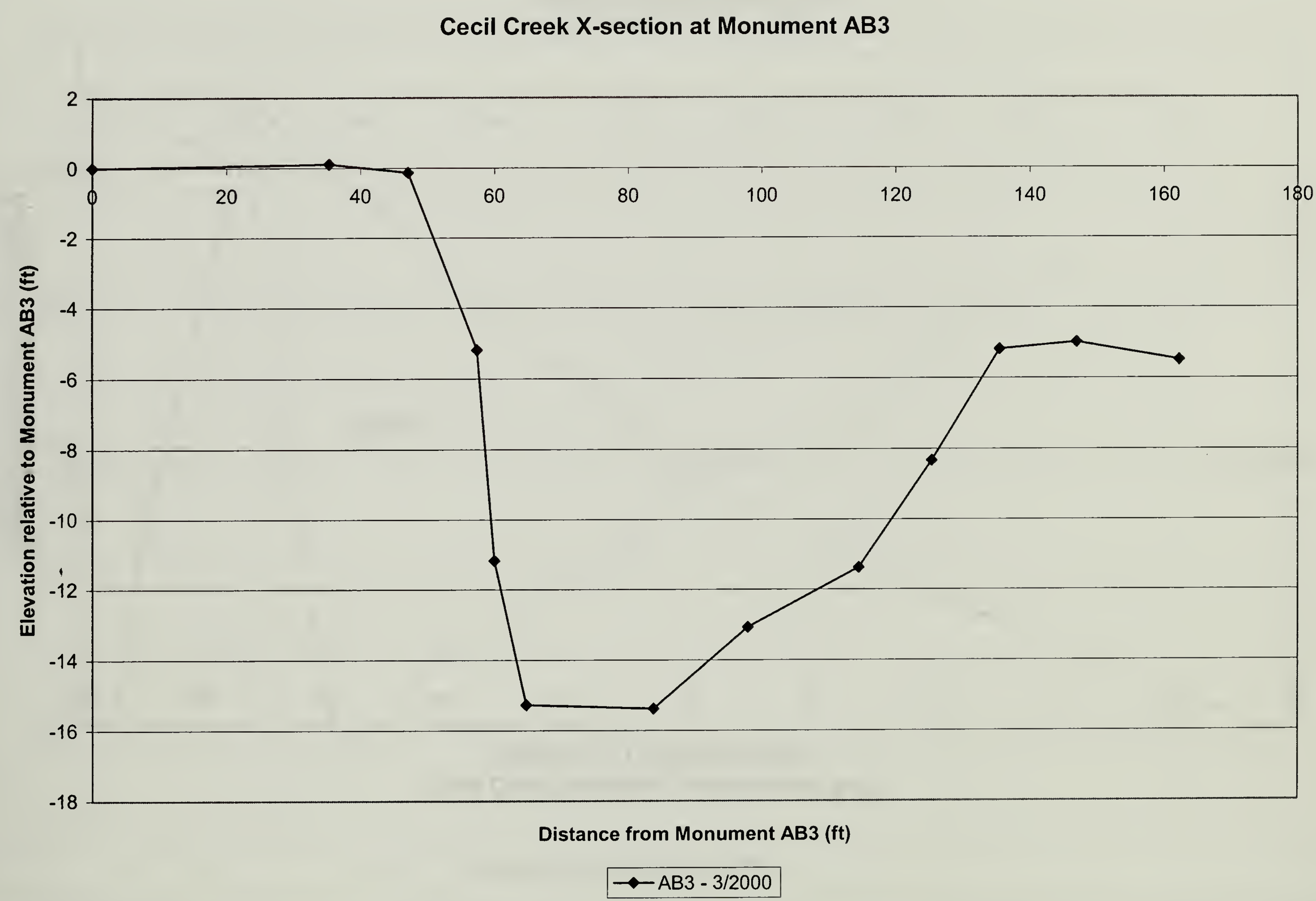

Cecil Creek X-section at Monument AB1
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
0
20
40
60
80
100
120
140
160
180
Elevation relative to Monument AB1 (ft)
Distance from Monument AB1 (ft)
AB1 - 3/2000


Cecil Creek X-section at Monument AB1
Close-up on Bankfull region
-12
-13
-14
-15
-16
-17
50
55
60
65
70
75
80
85
Bankfull
Elevation relative to Monument AB1 (ft)
Distance from Monument AB1 (ft)
AB1 - 3/2000

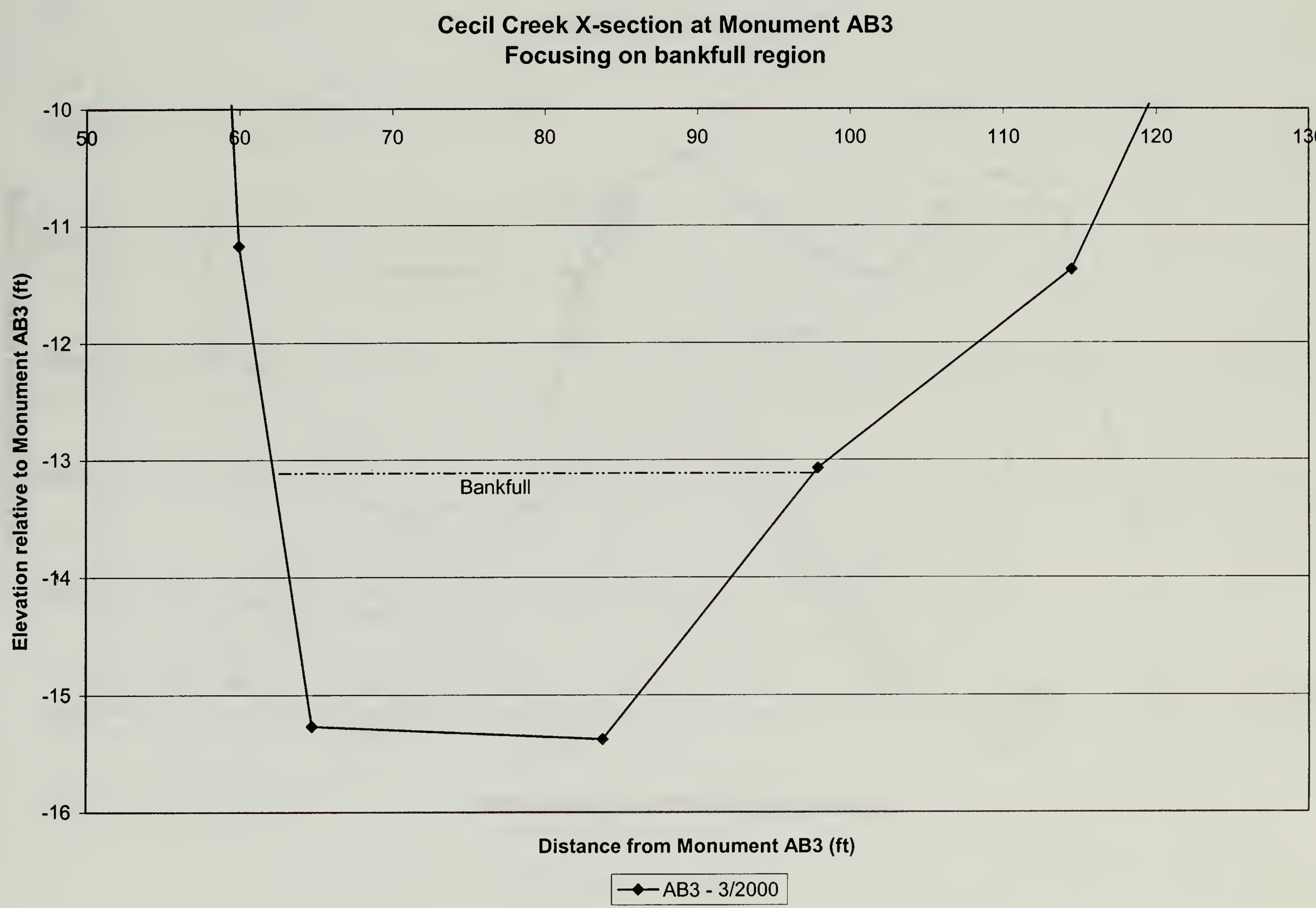

Cecil Creek X-Section AB2
Elevation relative to MonumentAB@ (ft)
0
-2
-4
-6
-8
-10
-12
-14
-16
0
20
40
60
80
100
120
140
160
Distancefrom Monument AB2 (ft)
Series1

Cecil Creek X-section at Monument AB2
Focusing on Bankfull region



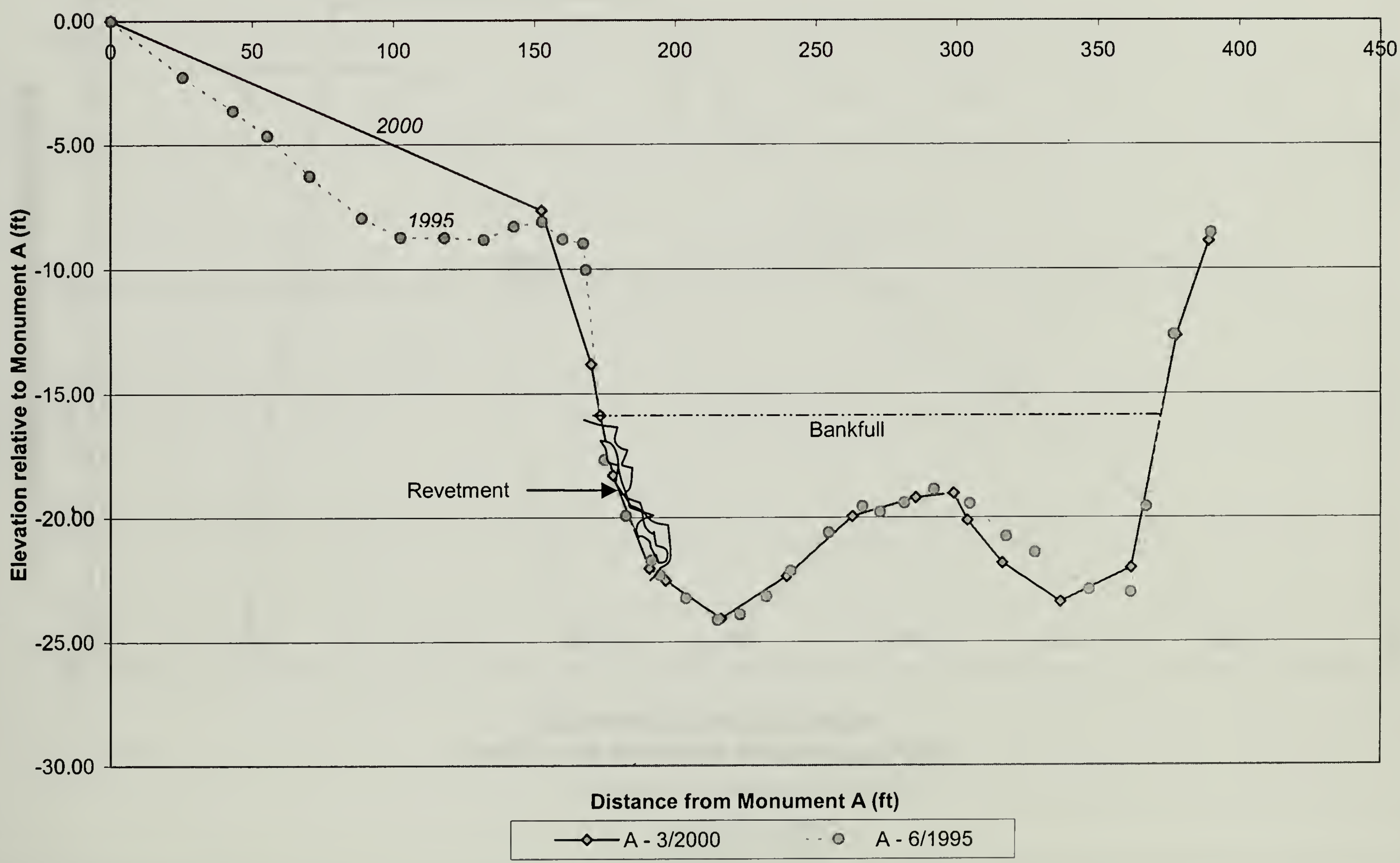


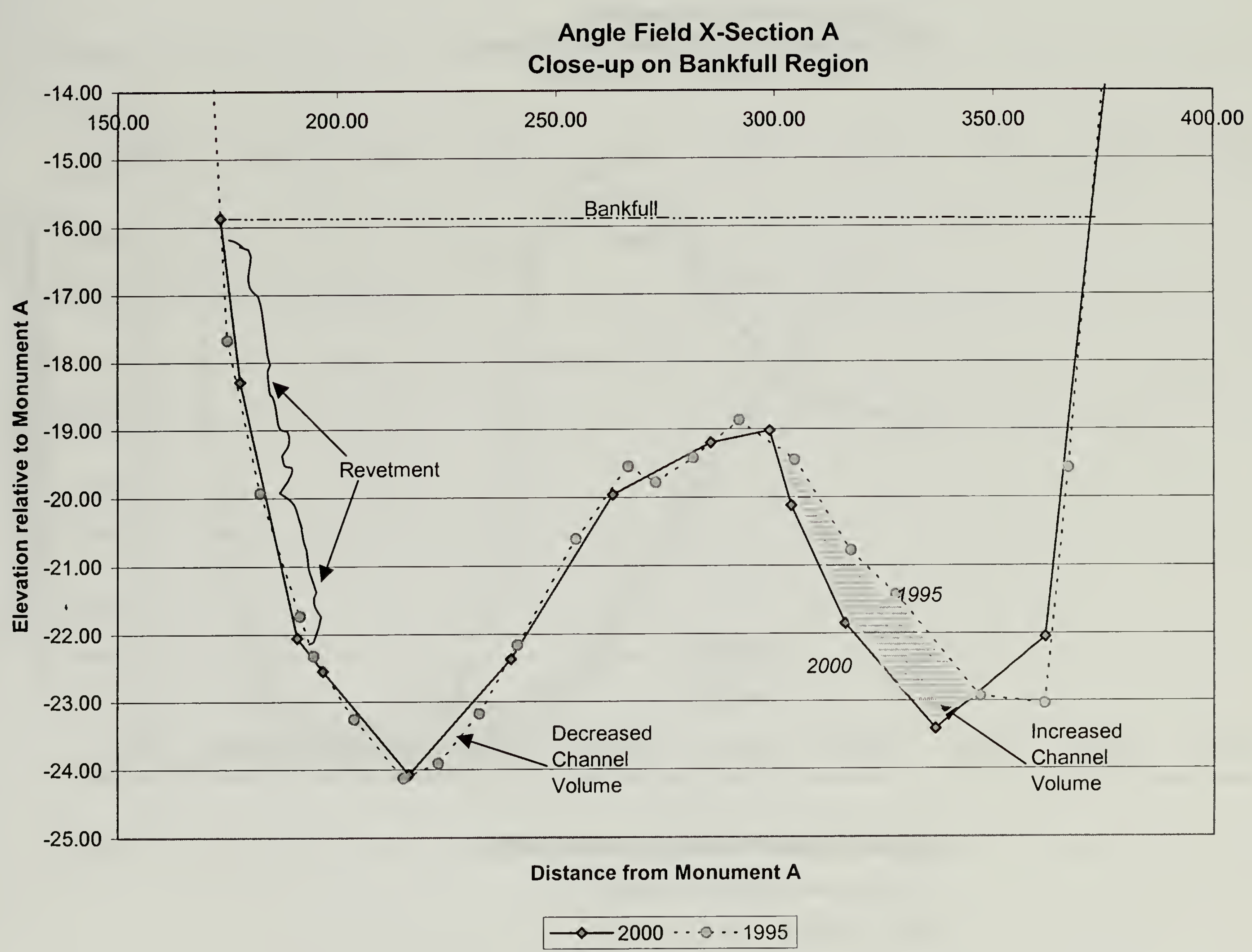
Cecil Creek X-section at Monument AB3
Elevation relative to Monument AB3 (ft)
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
0
20
40
60
80
100
120
140
160
180
Distance from Monument AB3 (ft)
AB3 - 3/2000



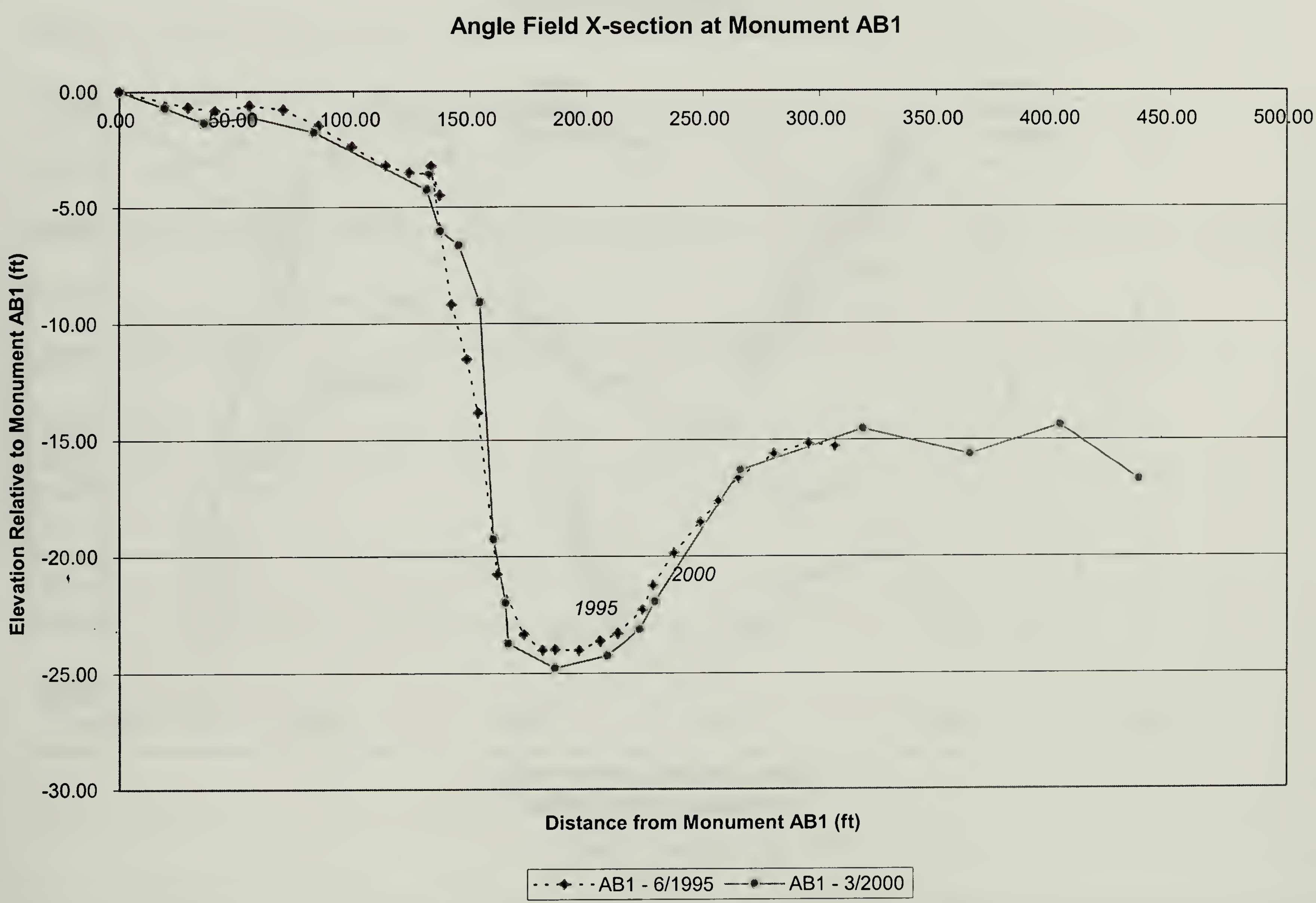
Cecil Creek X-section at Monument AB3
Focusing on bankfull region
Elevation relative to Monument AB3 (ft)
-10
-11
-12
-13
-14
-15
-16
50
60
70
80
90
100
110
120
130
Bankfull
Distance from Monument AB3 (ft)
AB3 - 3/2000

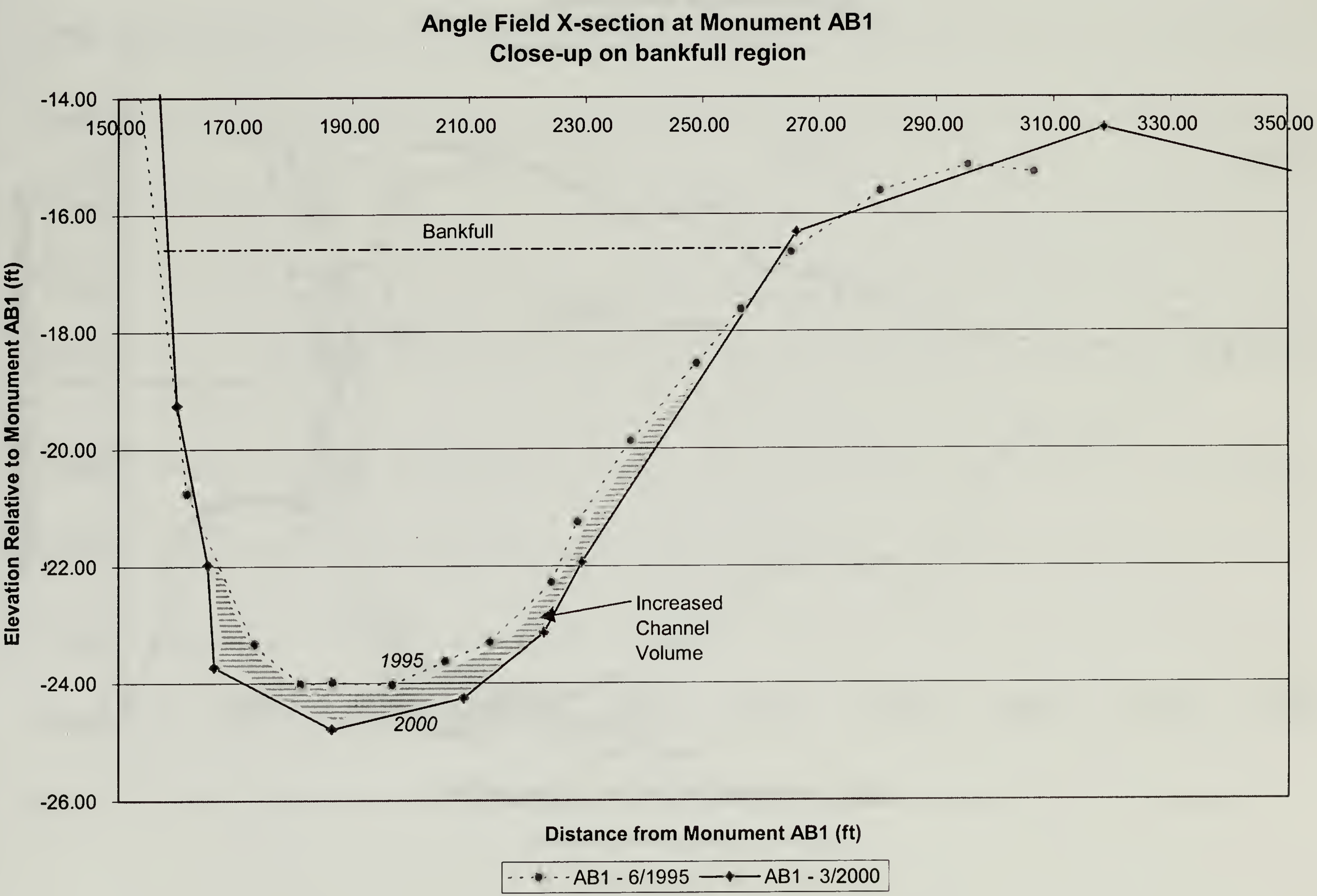
Angle Field X-section at Monument A



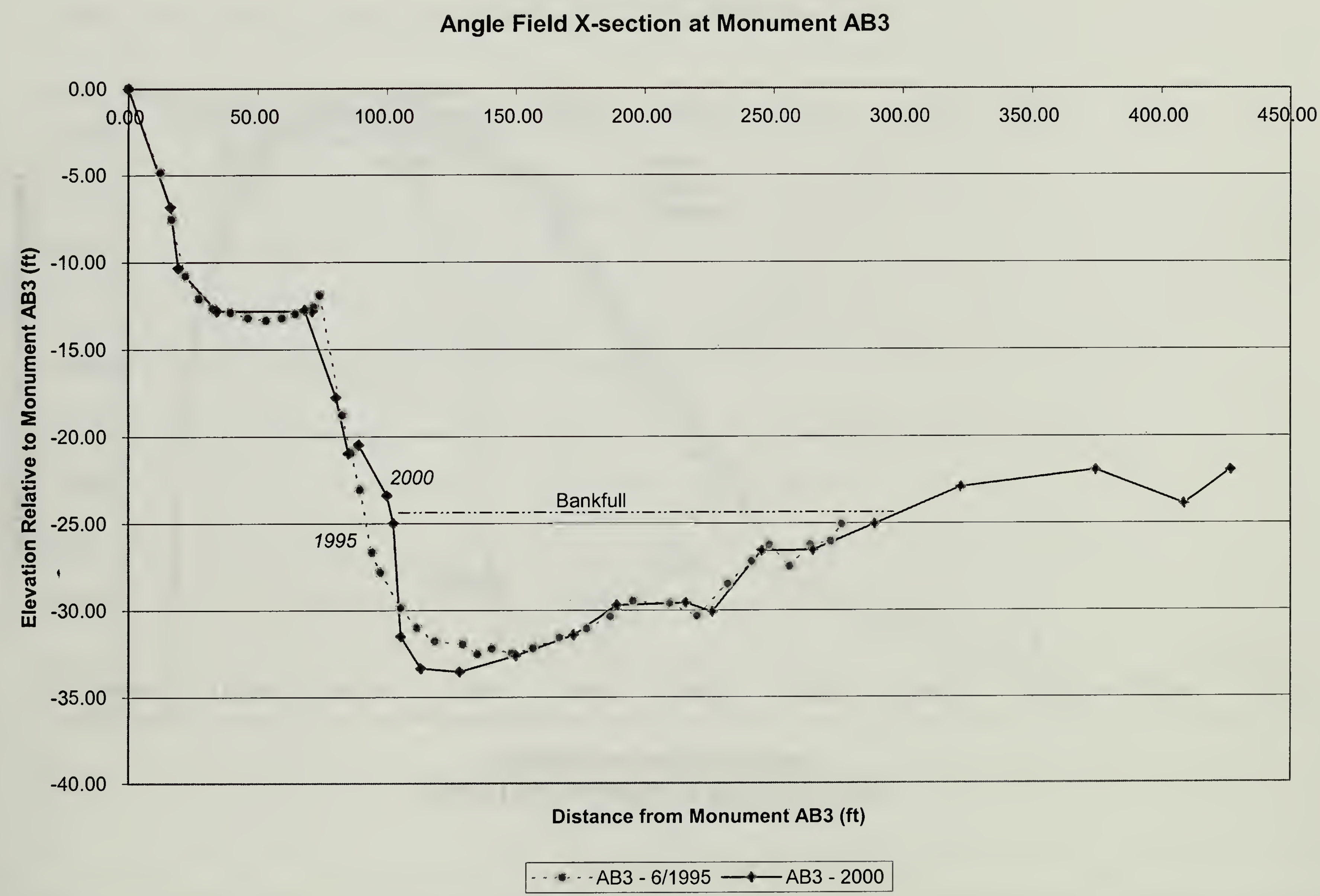


Angle Field X-Section A
Close-up on Bankfull Region
-14.00
-15.00
-16.00
-17.00
-18.00
-19.00
-20.00
-21.00
-22.00
-23.00
-24.00
-25.00
150.00
200.00
250.00
300.00
350.00
400.00
Elevation relative to Monument A
Bankfull
Revetment
1995
2000
Decreased Channel Volume
Increased Channel Volume
Distance from Monument A
2000
1995

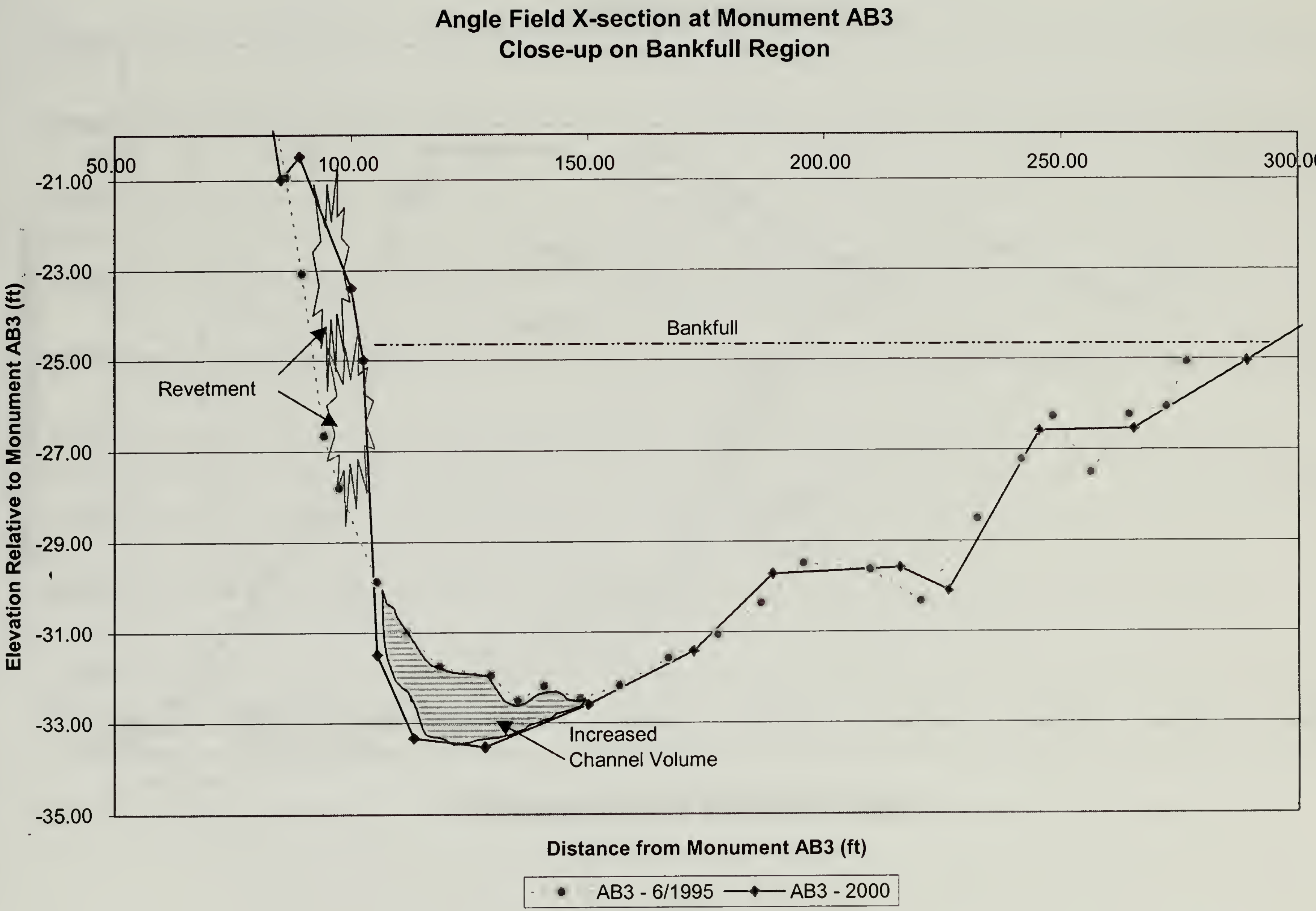

Angle Field X-section at Monument AB1
0.00
-5.00
-10.00
-15.00
-20.00
-25.00
-30.00
Elevation Relative to Monument AB1 (ft)
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
450.00
500.00
1995
2000
Distance from Monument AB1 (ft)
AB1 - 6/1995
AB1 - 3/2000



Angle Field X-section at Monument AB1
Close-up on bankfull region
-14.00
-16.00
-18.00
-20.00
-22.00
-24.00
-26.00
150.00
170.00
190.00
210.00
230.00
250.00
270.00
290.00
310.00
330.00
350.00
Bankfull
1995
2000
Increased
Channel
Volume
Elevation Relative to Monument AB1 (ft)
Distance from Monument AB1 (ft)
AB1 - 6/1995
AB1 - 3/2000

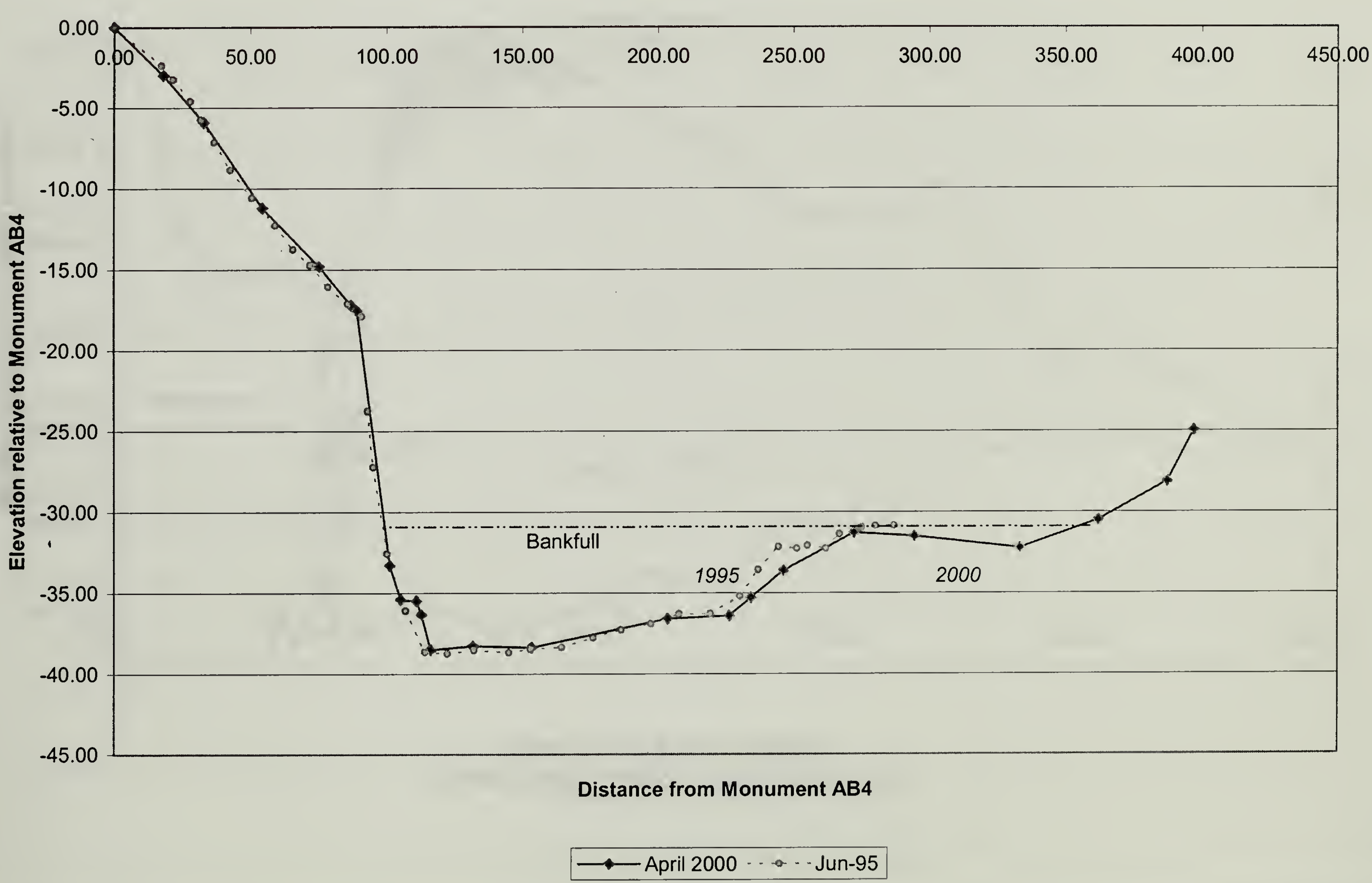


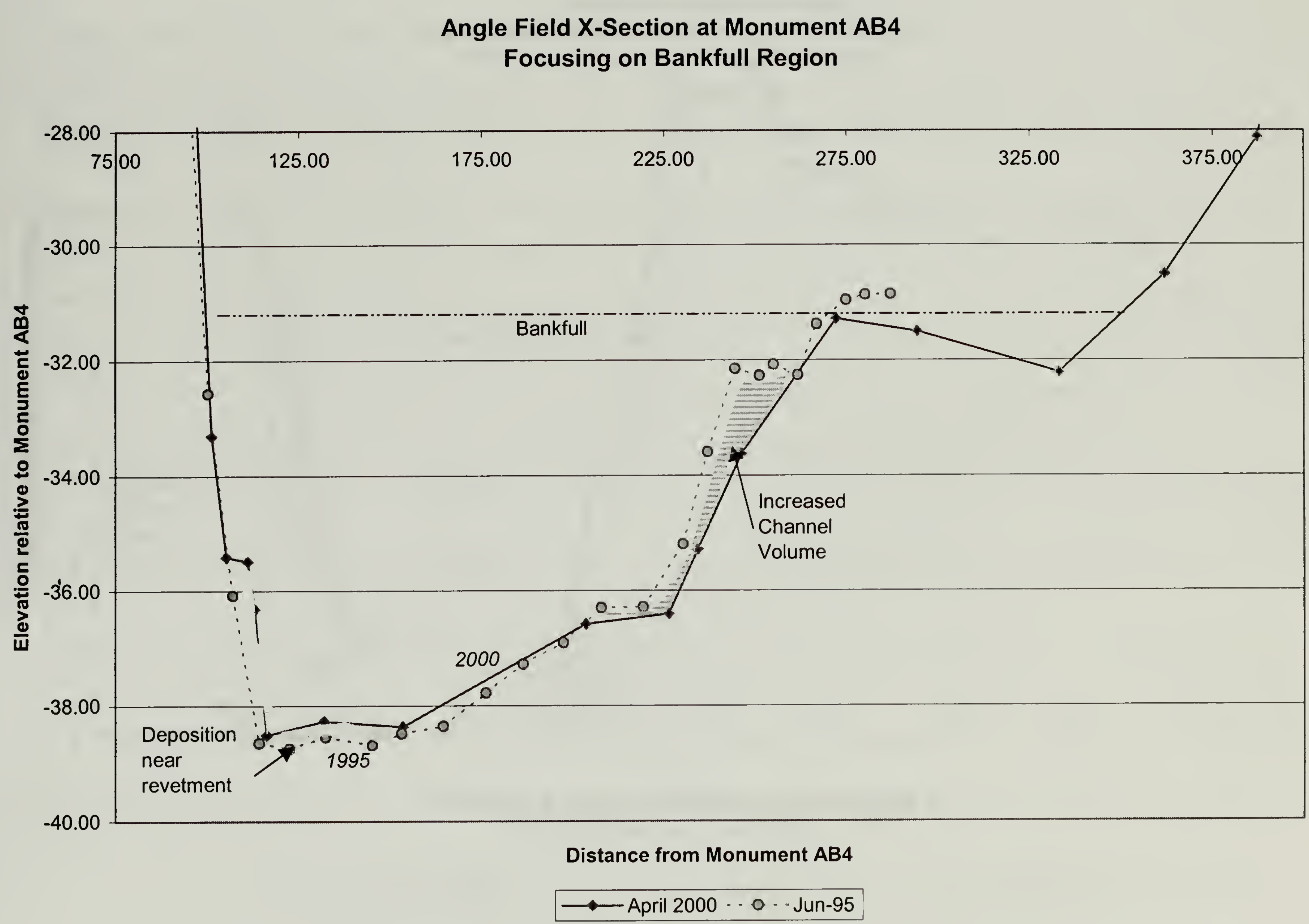
Angle Field X-section at Monument AB3
0.00
-5.00
-10.00
-15.00
-20.00
-25.00
-30.00
-35.00
-40.00
Elevation Relative to Monument AB3 (ft)
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
450.00
2000
1995
Bankfull
Distance from Monument AB3 (ft)
AB3 - 6/1995
AB3 - 2000

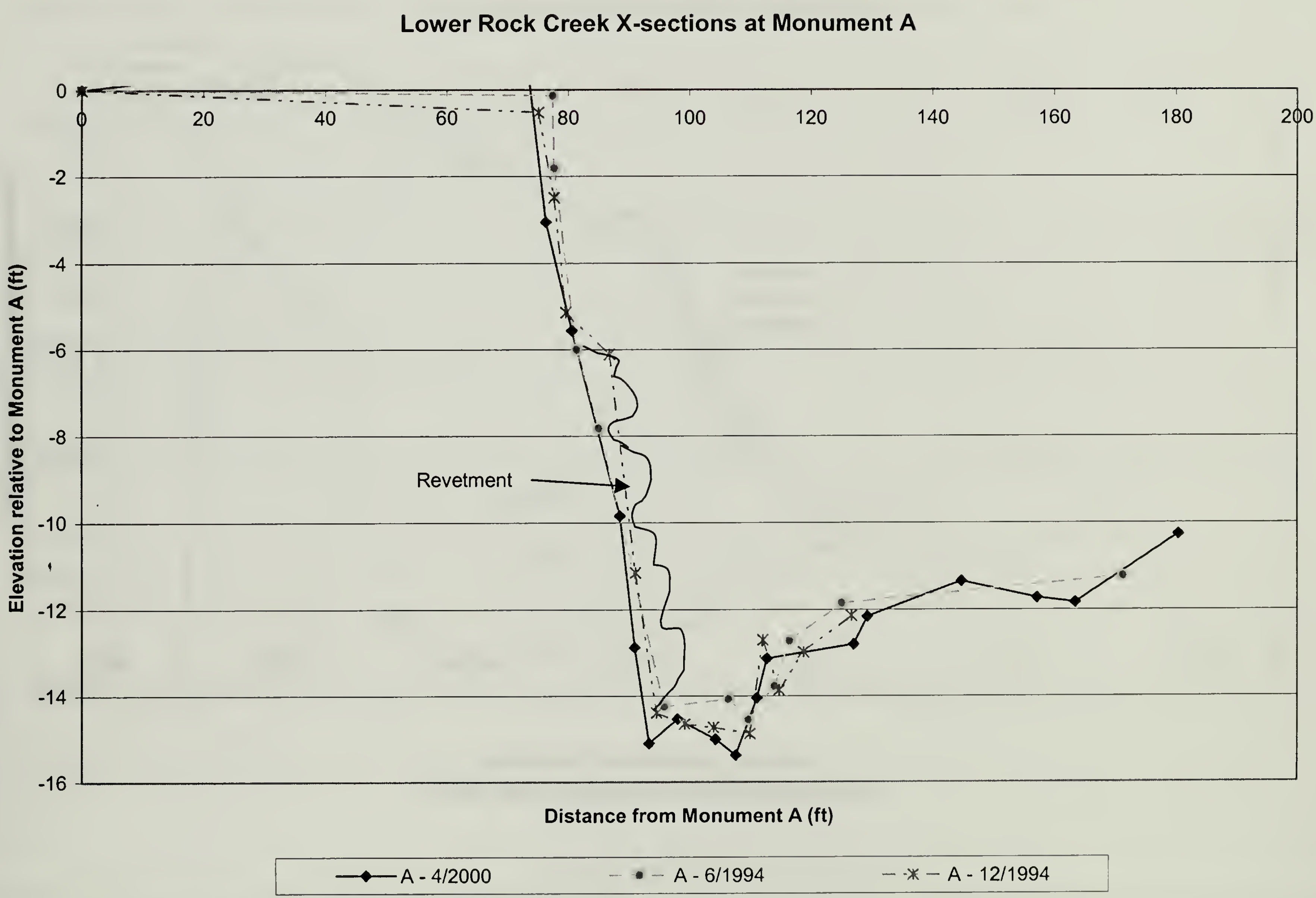


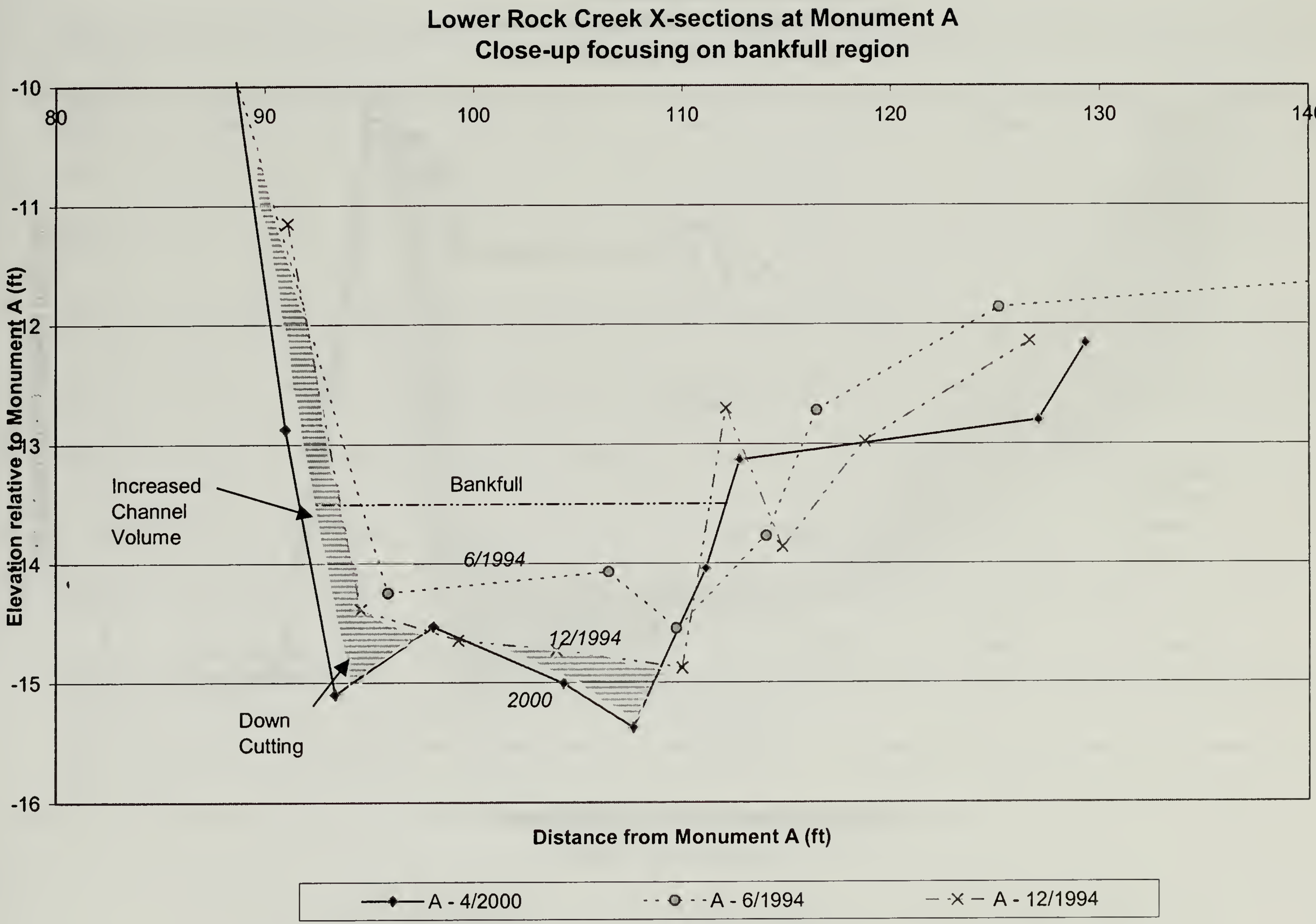
Angle Field X-section at Monument AB3
Close-up on Bankfull Region
Elevation Relative to Monument AB3 (ft)
-21.00
-23.00
-25.00
-27.00
-29.00
-31.00
-33.00
-35.00
50.00
100.00
150.00
200.00
250.00
300.00
Bankfull
Revetment
Increased
Channel Volume
Distance from Monument AB3 (ft)
AB3 - 6/1995
AB3 - 2000

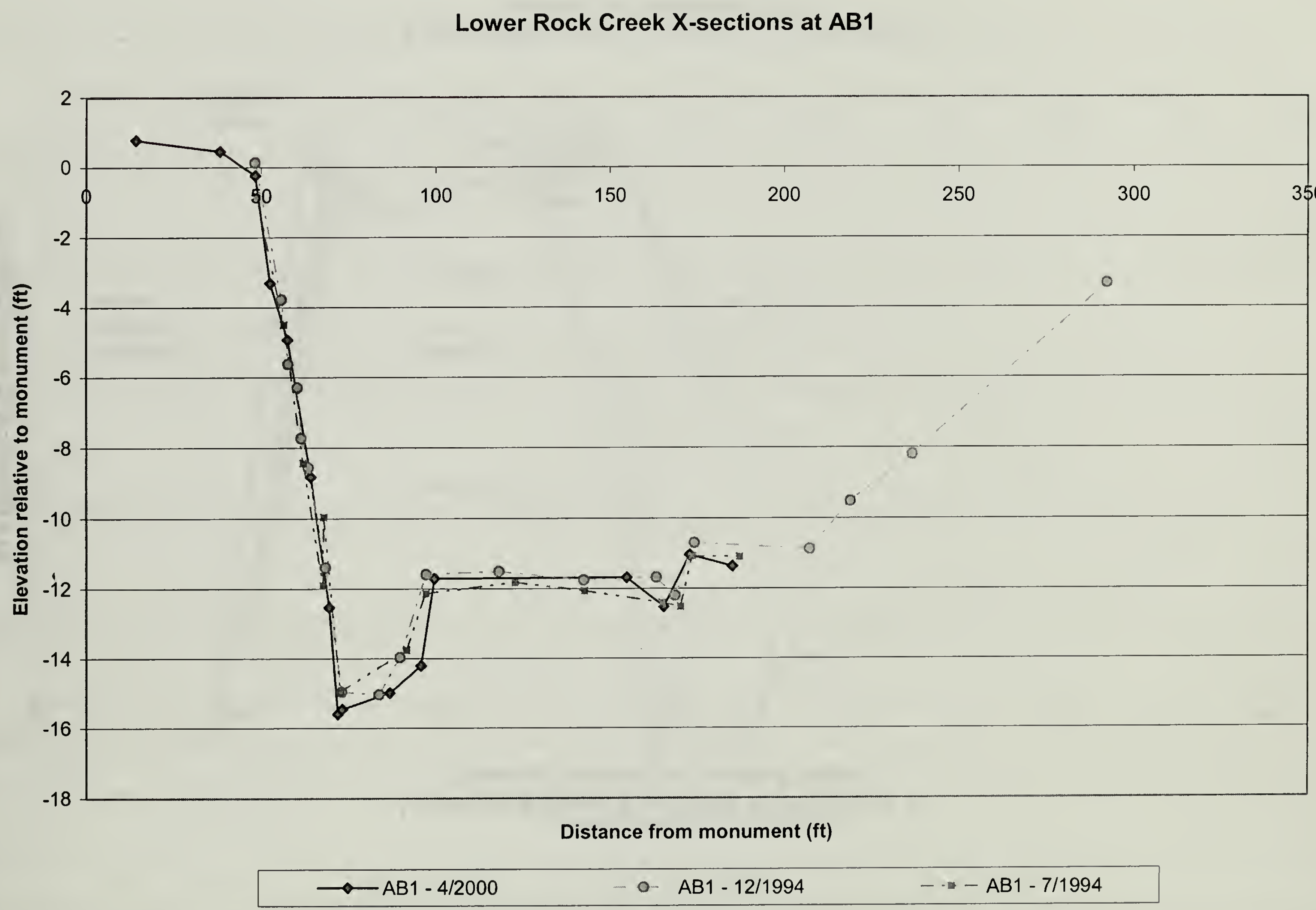
Angle Field X-Section at Monument AB4

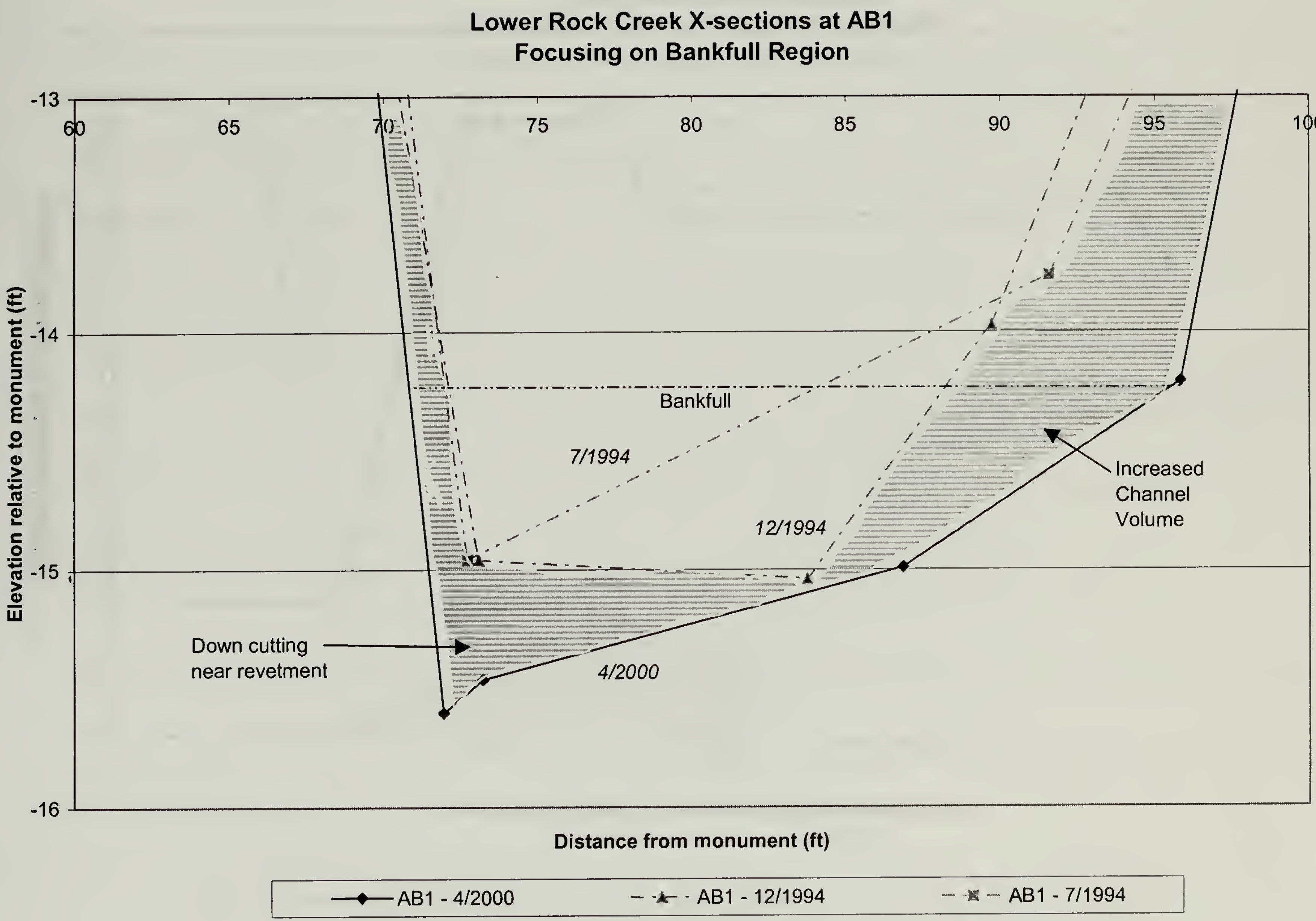



Angle Field X-Section at Monument AB4
Focusing on Bankfull Region
-28.00
-30.00
-32.00
-34.00
-36.00
-38.00
-40.00
75.00
125.00
175.00
225.00
275.00
325.00
375.00
Bankfull
Increased
Channel
Volume
2000
1995
Deposition
near
revetment
Elevation relative to Monument AB4
Distance from Monument AB4
April 2000
Jun-95


Lower Rock Creek X-sections at Monument A
Elevation relative to Monument A (ft)
0
-2
-4
-6
-8
-10
-12
-14
-16
0
20
40
60
80
100
120
140
160
180
200
Revetment
Distance from Monument A (ft)
A - 4/2000
A - 6/1994
A - 12/1994

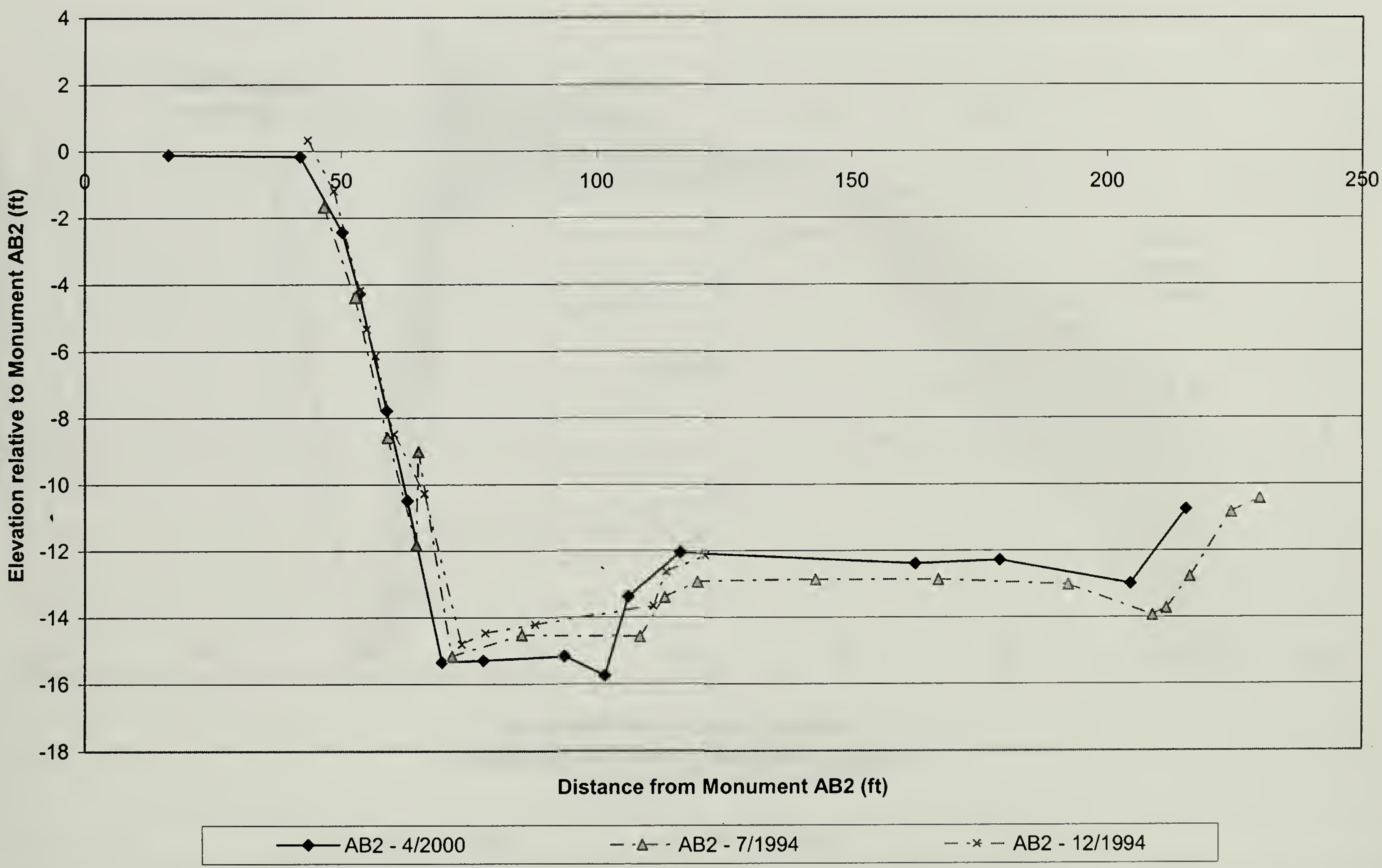

Lower Rock Creek X-sections at Monument A
Close-up focusing on bankfull region
Elevation relative to Monument A (ft)
Distance from Monument A (ft)
Bankfull
Increased
Channel
Volume
Down
Cutting
6/1994
12/1994
2000
A - 4/2000
A - 6/1994
A - 12/1994

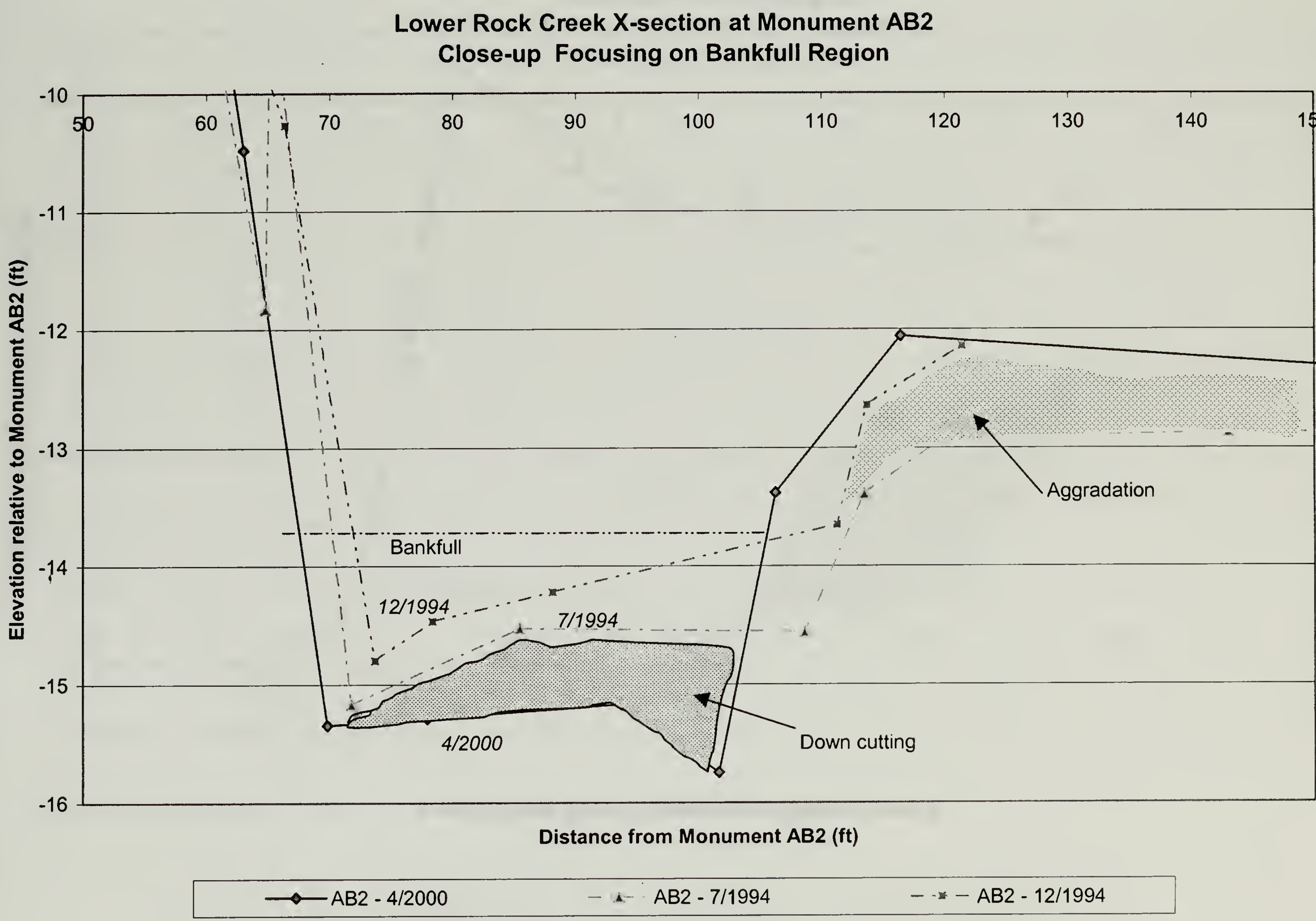

Lower Rock Creek X-sections at AB1
Elevation relative to monument (ft)
Distance from monument (ft)
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
0
50
100
150
200
250
300
350
AB1 - 4/2000
AB1 - 12/1994
AB1 - 7/1994

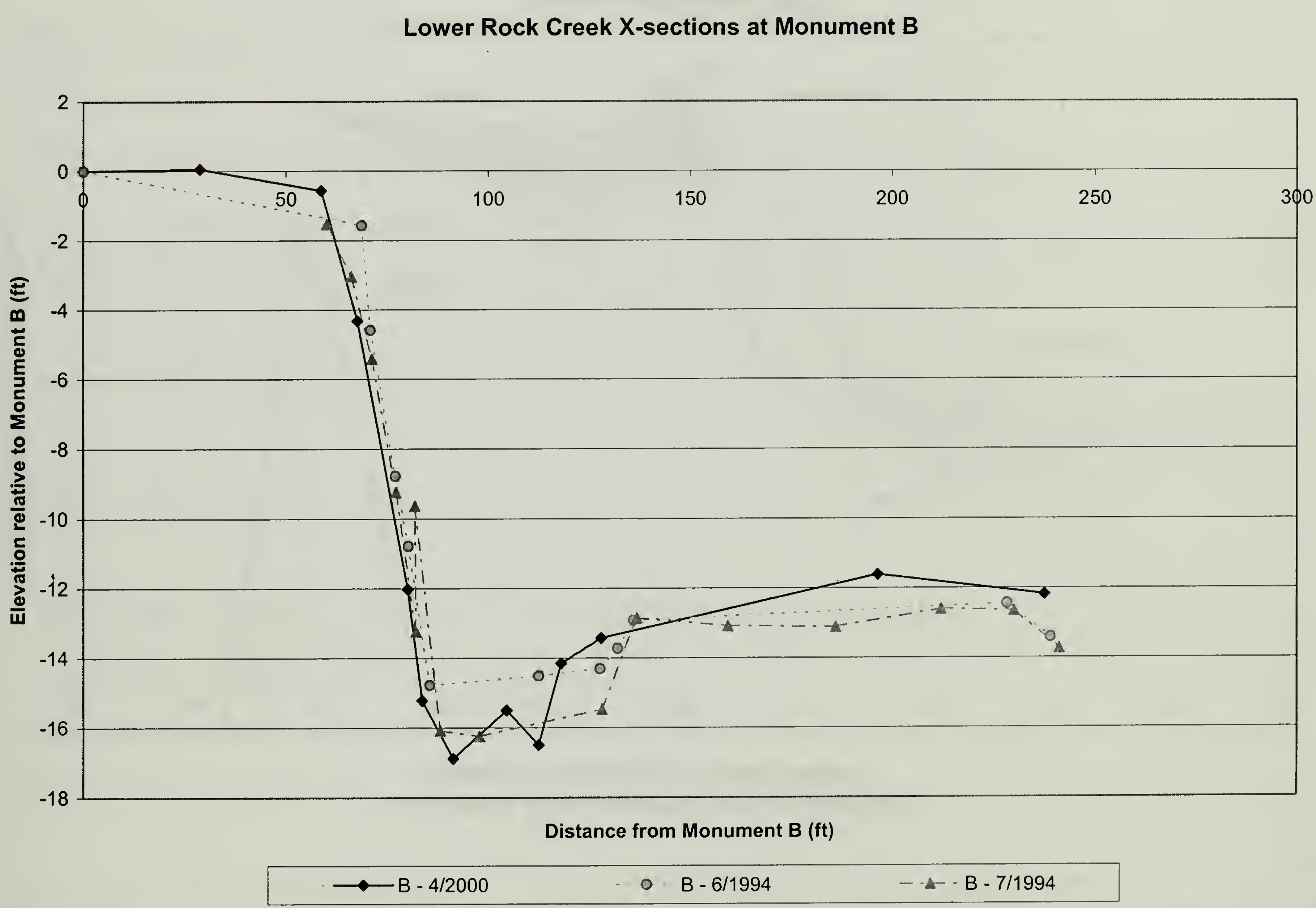


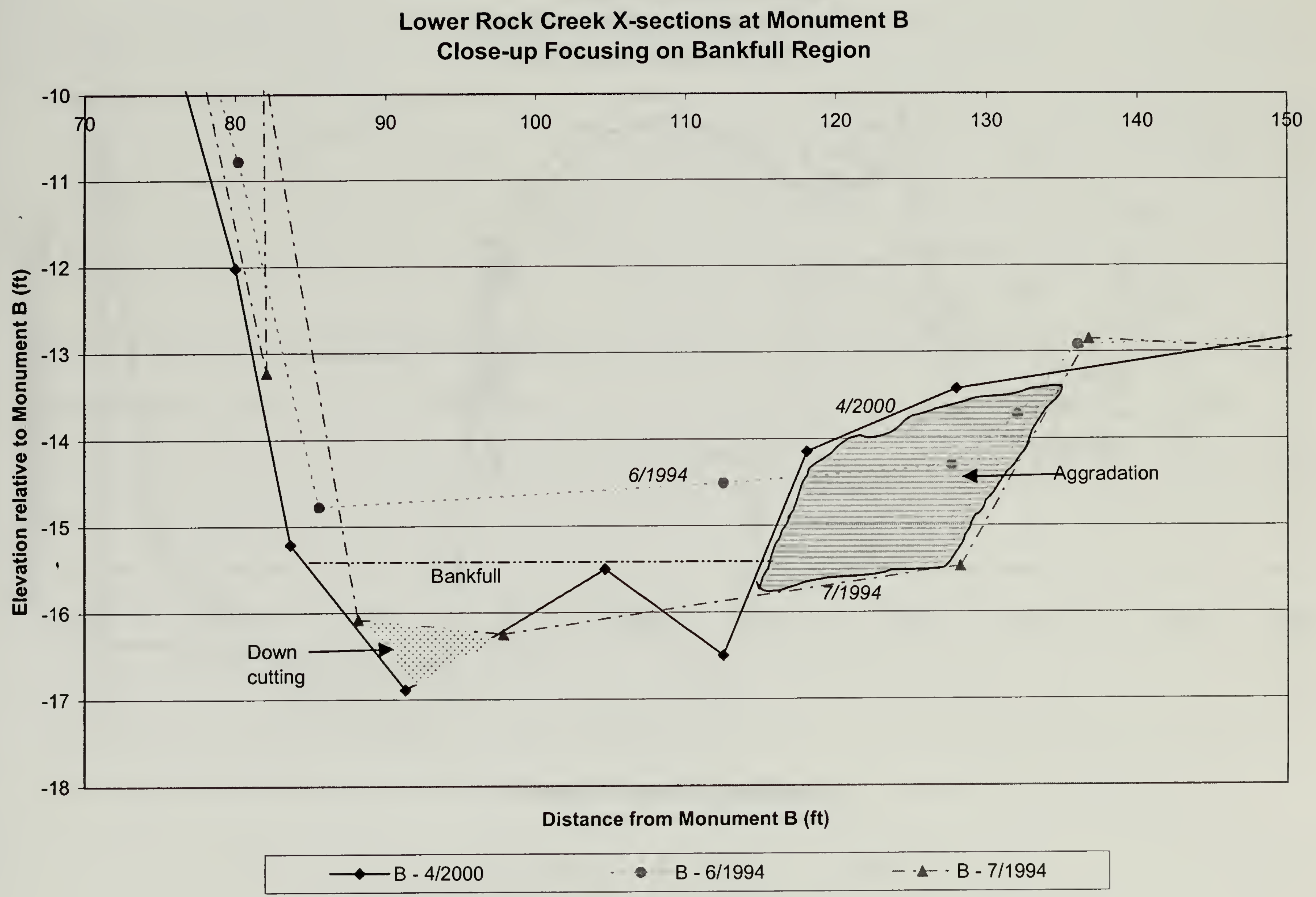
Lower Rock Creek X-sections at AB1
Focusing on Bankfull Region
Elevation relative to monument (ft)
-13
-14
-15
-16
60
65
70
75
80
85
90
95
100
Bankfull
7/1994
12/1994
4/2000
Increased Channel Volume
Down cutting near revetment
Distance from monument (ft)
AB1 - 4/2000
AB1 - 12/1994
AB1 - 7/1994

Lower Rock Creek X-section at Monument AB2

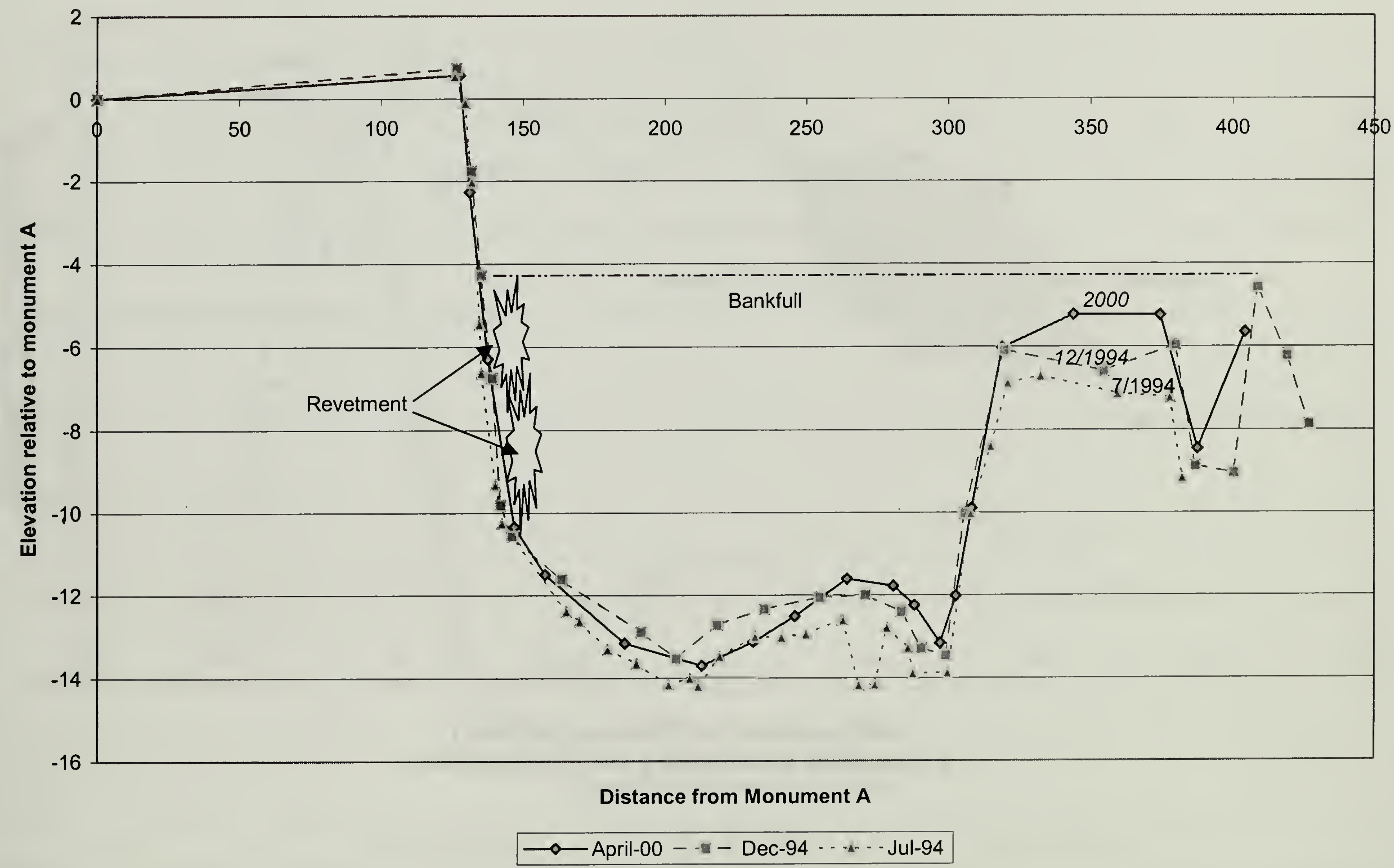



Lower Rock Creek X-section at Monument AB2
Close-up Focusing on Bankfull Region
Elevation relative to Monument AB2 (ft)
Distance from Monument AB2 (ft)
Bankfull
12/1994
7/1994
4/2000
Aggradation
Down cutting
AB2 - 4/2000
AB2 - 7/1994
AB2 - 12/1994
-10
-11
-12
-13
-14
-15
-16
50
60
70
80
90
100
110
120
130
140
150

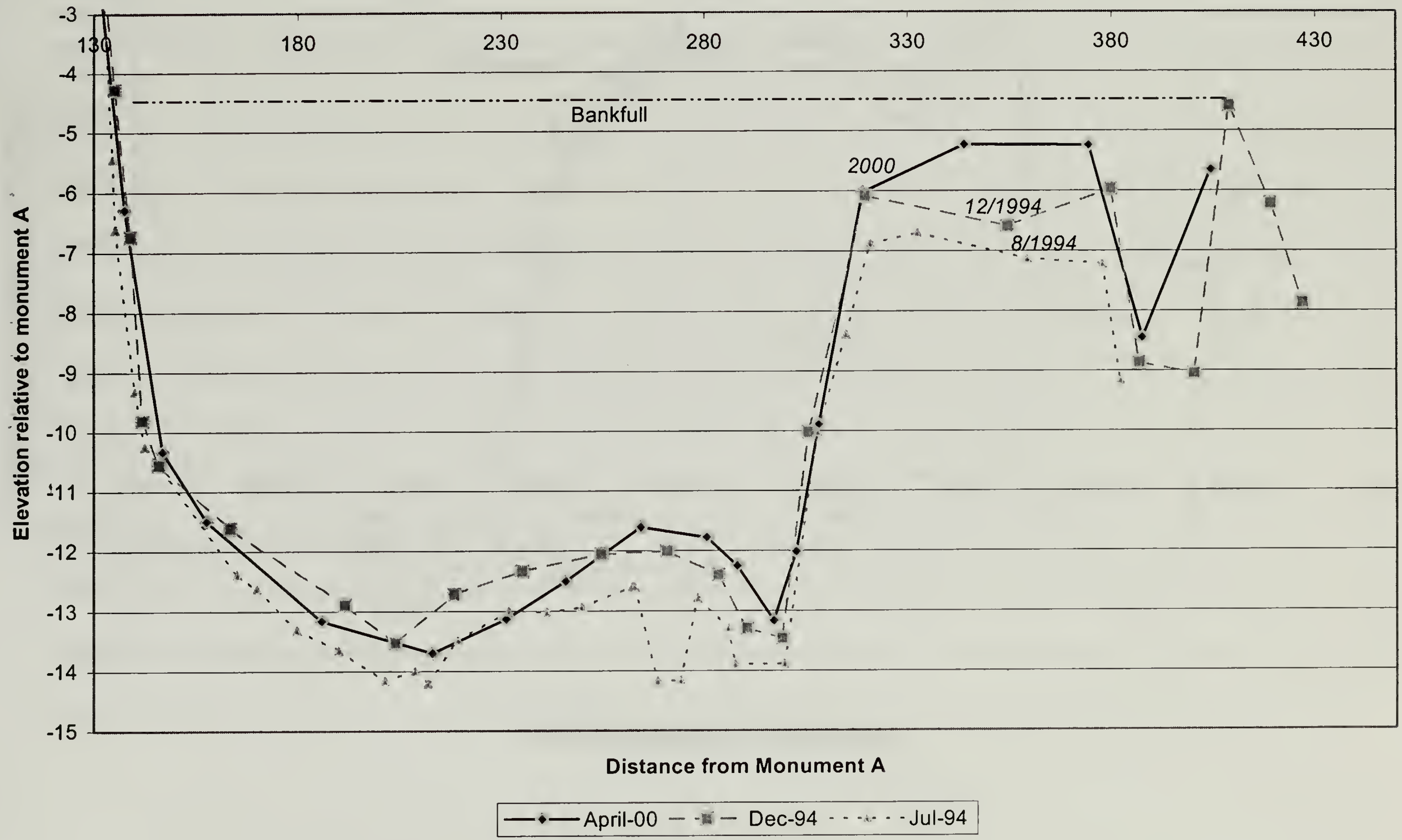

Lower Rock Creek X-sections at Monument B
Elevation relative to Monument B (ft)
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
0
50
100
150
200
250
300
Distance from Monument B (ft)
B - 4/2000
B - 6/1994
B - 7/1994

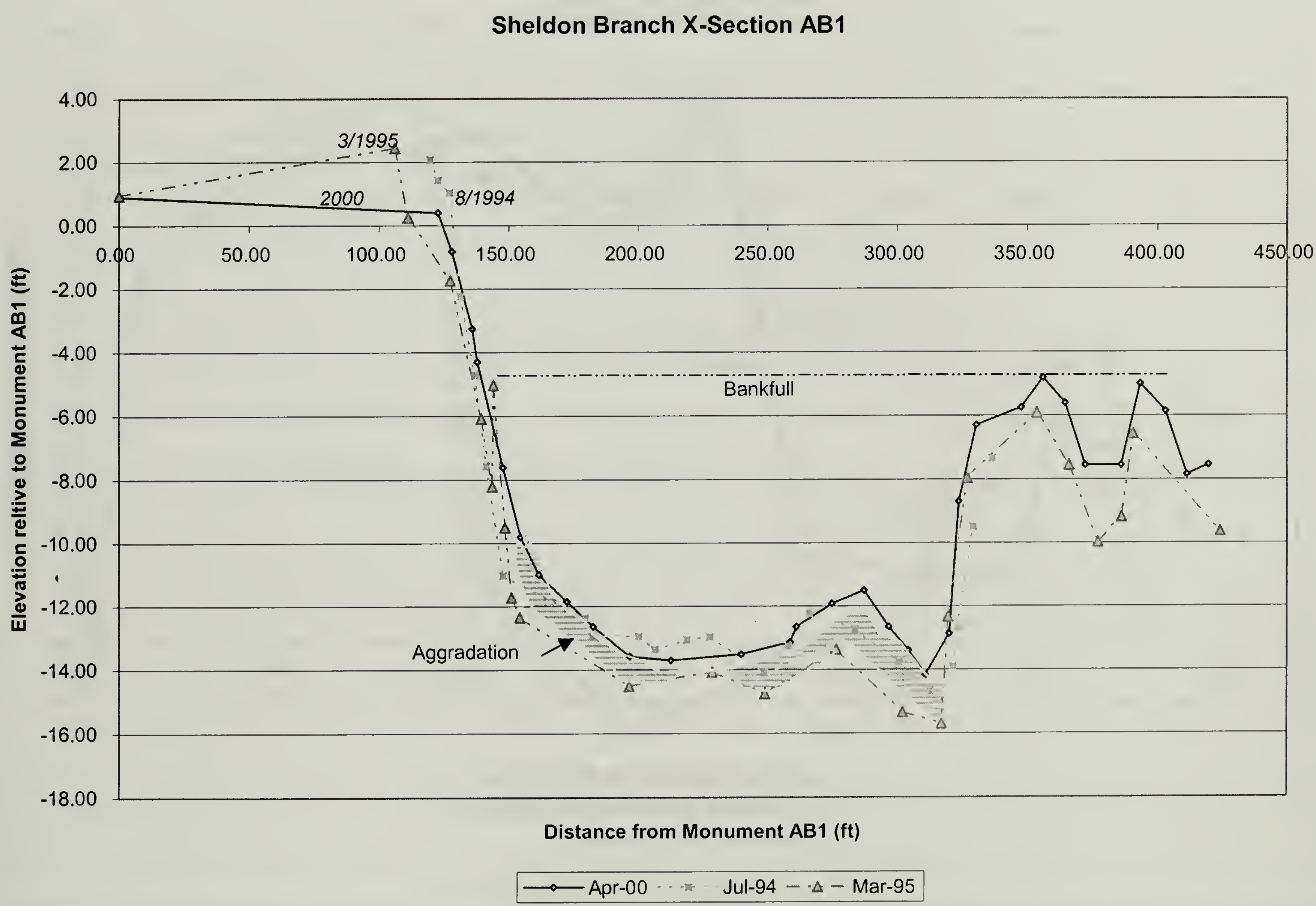

Lower Rock Creek X-sections at Monument B
Close-up Focusing on Bankfull Region
Elevation relative to Monument B (ft)
-10
-11
-12
-13
-14
-15
-16
-17
-18
70
80
90
100
110
120
130
140
150
4/2000
6/1994
7/1994
Aggradation
Bankfull
Down
cutting
Distance from Monument B (ft)
B - 4/2000
B - 6/1994
B - 7/1994

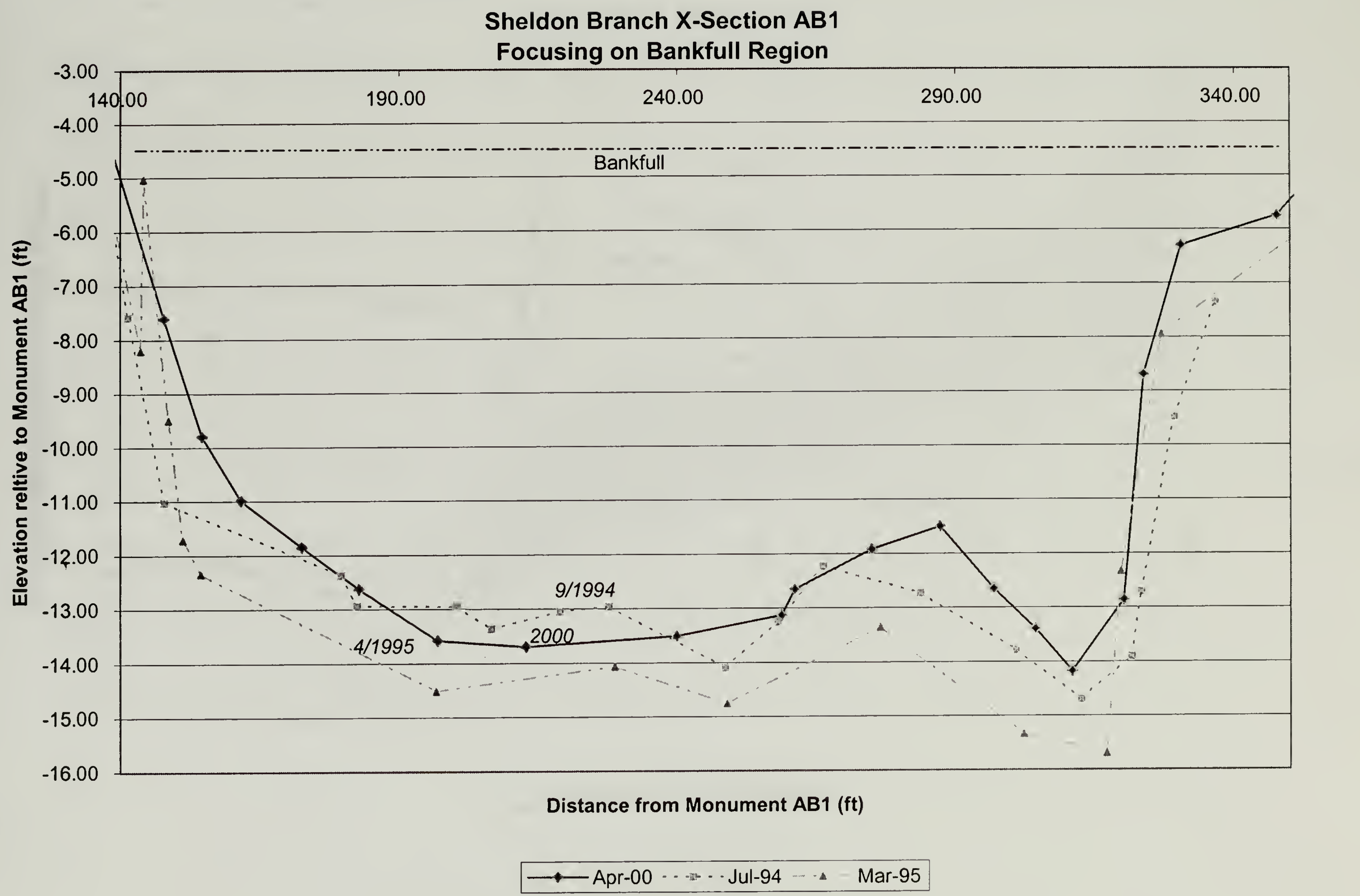
Sheldon Branch X-Section A



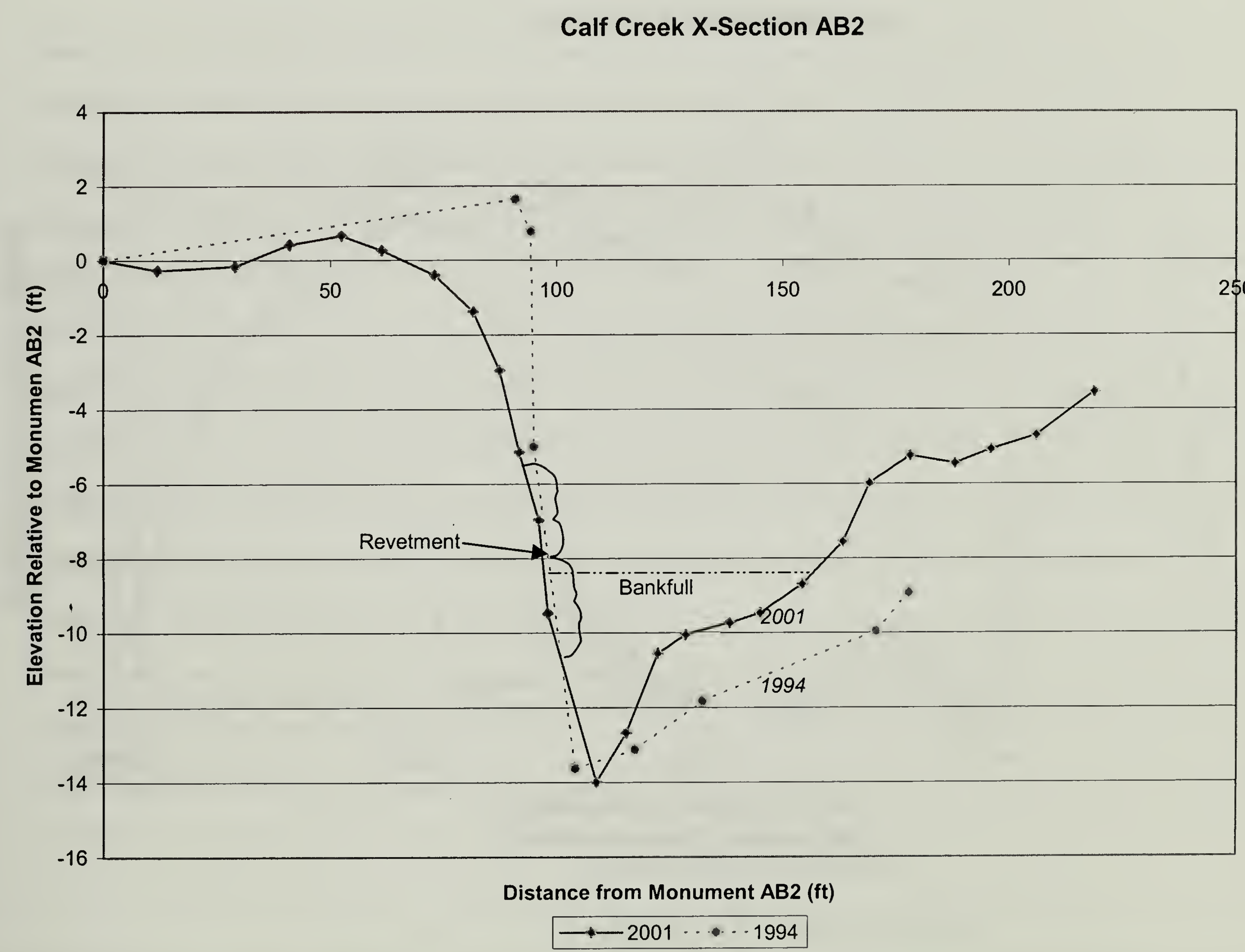
Sheldon Branch X-Section A
Focusing on Bankfull region



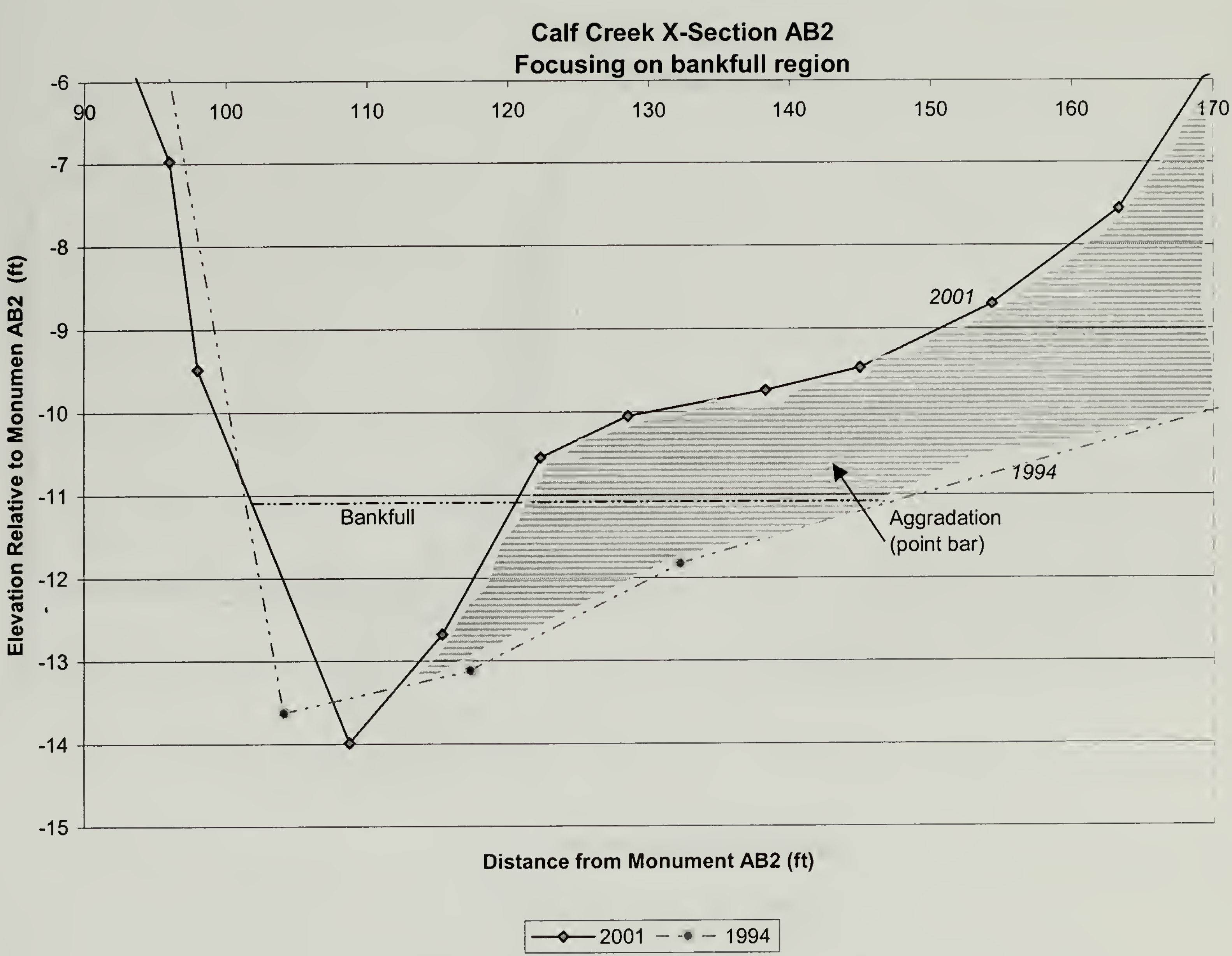

Sheldon Branch X-Section AB1
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
-14.00
-16.00
-18.00
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
450.00
3/1995
2000
8/1994
Bankfull
Aggradation
Elevation reltive to Monument AB1 (ft)
Distance from Monument AB1 (ft)
Apr-00
Jul-94
Mar-95

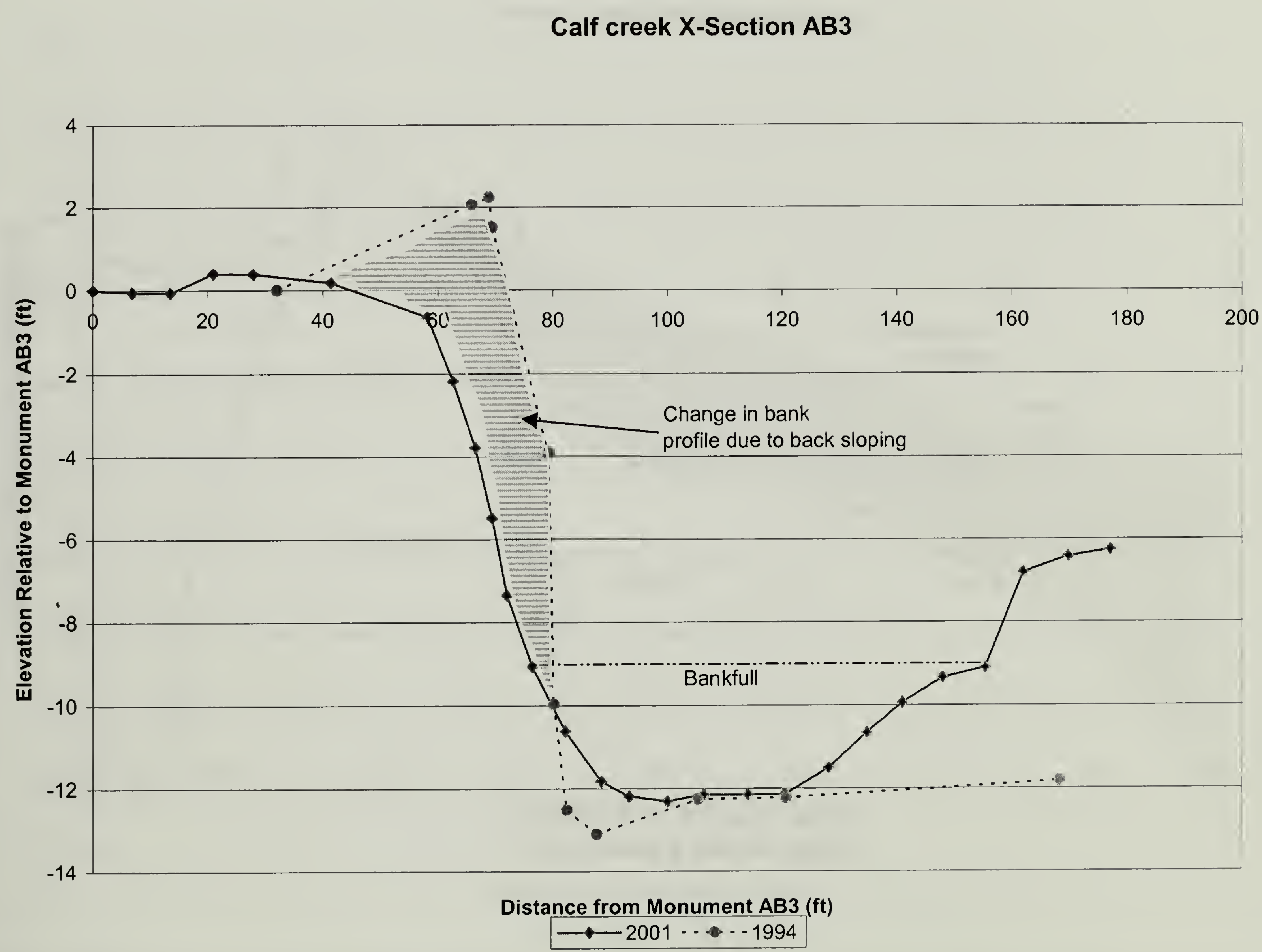


Sheldon Branch X-Section AB1
Focusing on Bankfull Region
Elevation reltive to Monument AB1 (ft)
-3.00
-4.00
-5.00
-6.00
-7.00
-8.00
-9.00
-10.00
-11.00
-12.00
-13.00
-14.00
-15.00
-16.00
140.00
190.00
240.00
290.00
340.00
Bankfull
9/1994
2000
4/1995
Distance from Monument AB1 (ft)
Apr-00
Jul-94
Mar-95



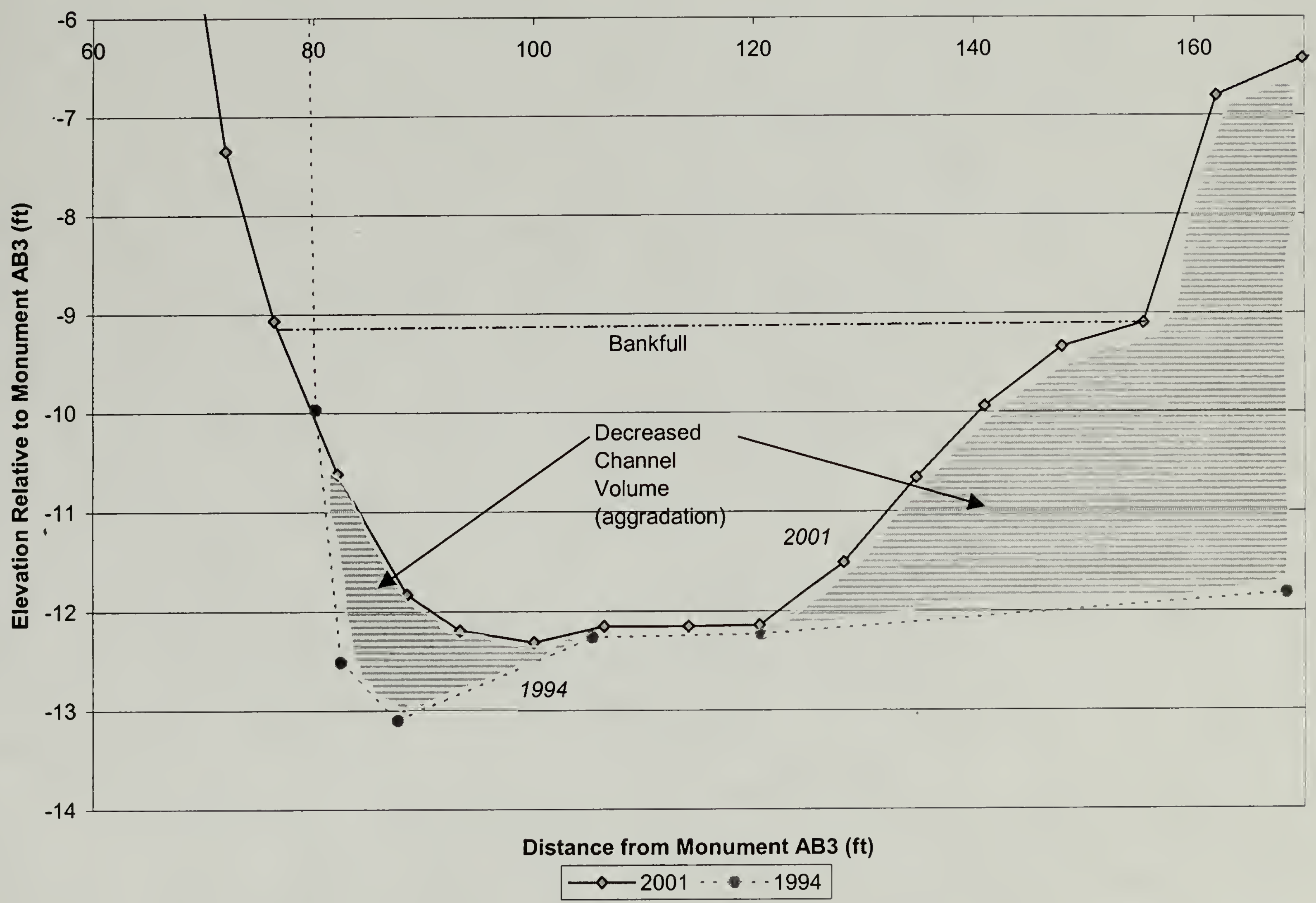
Calf Creek X-Section AB2
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
0
50
100
150
200
250
Elevation Relative to Monumen AB2 (ft)
Revetment
Bankfull
2001
1994
Distance from Monument AB2 (ft)
2001
1994

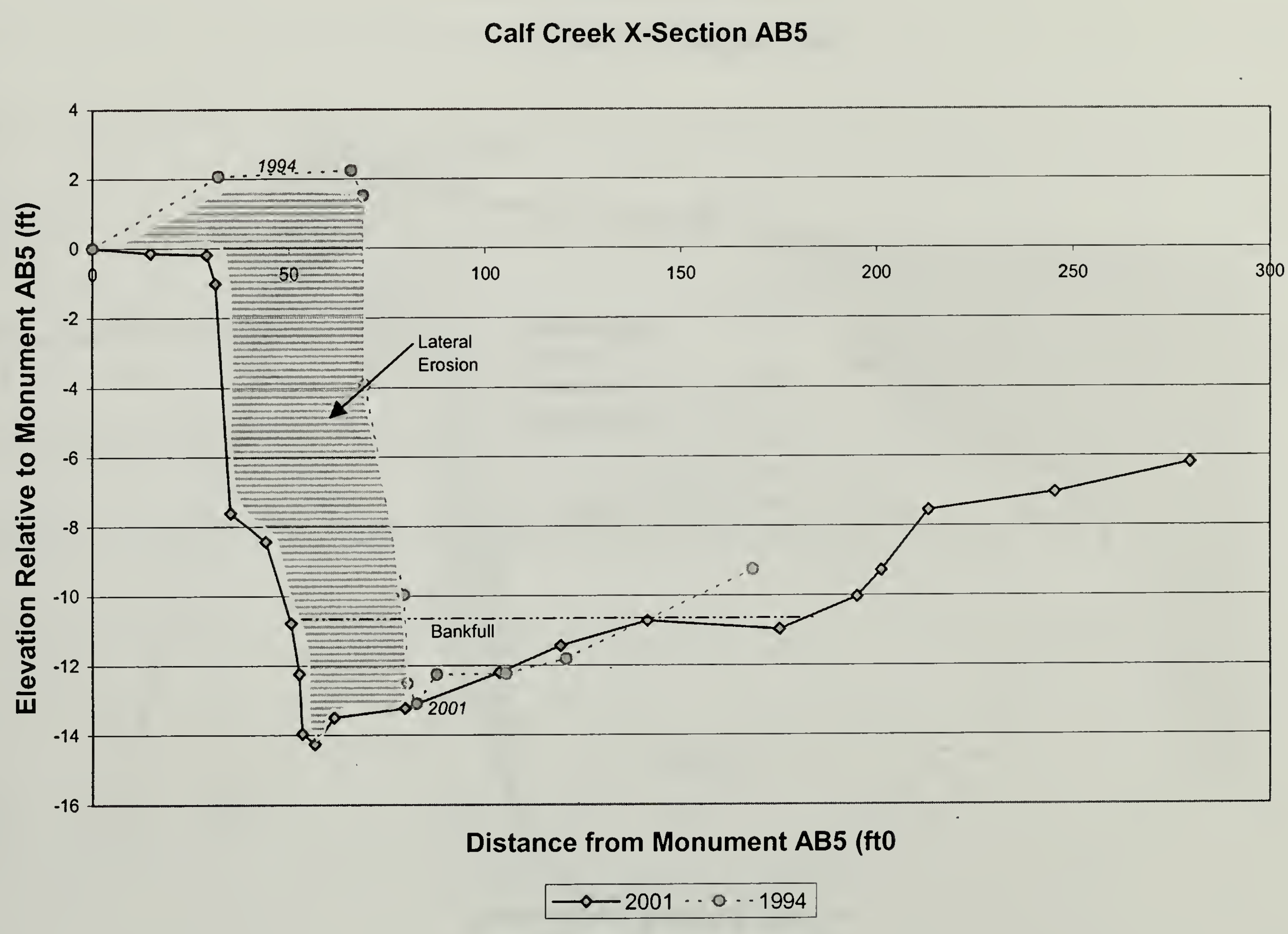

Calf Creek X-Section AB2
Focusing on bankfull region
Elevation Relative to Monumen AB2 (ft)
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
90
100
110
120
130
140
150
160
170
2001
1994
Bankfull
Aggradation
(point bar)
Distance from Monument AB2 (ft)
2001
1994



Calf creek X-Section AB3
Elevation Relative to Monument AB3 (ft)
4
2
0
-2
-4
-6
-8
-10
-12
-14
0
20
40
60
80
100
120
140
160
180
200
Change in bank
profile due to back sloping
Bankfull
Distance from Monument AB3 (ft)
2001
1994

Calf creek X-Section AB3
Close-up on Bankfull Region





Calf Creek X-Section AB5
Elevation Relative to Monument AB5 (ft)
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
0
50
100
150
200
250
300
1994
Lateral
Erosion
Bankfull
2001
Distance from Monument AB5 (ft0
2001
1994

Buffalo National River

RESOURCE MANAGEMENT DIVISION